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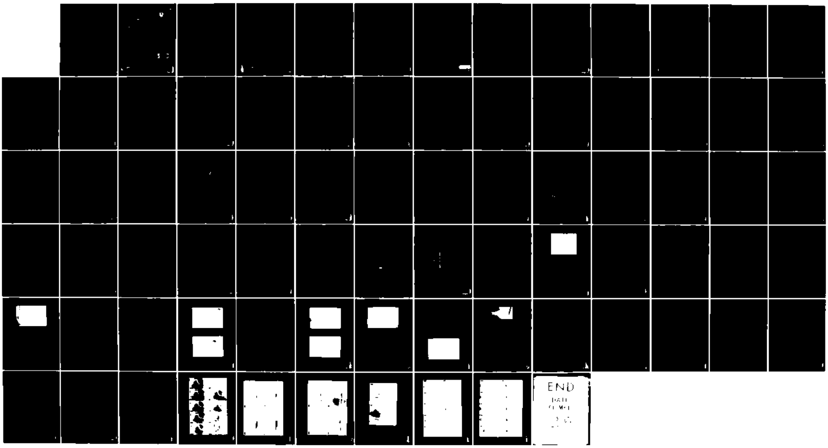

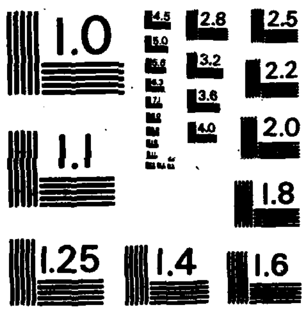

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CRASHWORTHY [redacted] CONTROL STICK
CYCLIC

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November 1983

Final Report for Period October 1982 - June 1983

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Prepared for

APPLIED TECHNOLOGY LABORATORY
U. S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES (AVRADCOM)
Fort Eustis, Va. 23604

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APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report provides the results of a preliminary concept design effort which demonstrates the feasibility of designing a crashworthy cyclic control stick that can separate under a reduced impact load during a crash and thus reduce the injury potential to the crew from impact with the stick. A prototype stick design was fabricated and subjected to static tests which simulated emergency operational loads and dynamic tests approximating the impact of the stick by a crew member using a five-point restraint harness. Standard UH-60 and AH-1 cyclic control sticks were subjected to the same tests for comparison, and results showed that the crashworthy cyclic control sticks reduced the initial impact forces by 44 and 68 percent for the UH-60 and AH-1S respectively, with a 50-percent reduction in the duration.

Results of this effort are still preliminary, and additional effort is required to adequately evaluate the crashworthiness characteristics of the cyclic control stick.

Mr. Harold Holland of the Aeronautical Systems Division served as technical monitor for this program.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In helicopter crashes, a potential source of injury is crewmember impact with the cyclic control stick. This program sought to alleviate that hazard through the development of a crashworthy cyclic control stick retrofittable to the UH-60A Black Hawk and AH-1S Cobra helicopters. Concepts examined for this application included those employing frangible, deformable, telescoping, collapsing, and separating sticks, as well as tube cutters. The selected design was a slip joint separating stick, with an energy → over

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absorber, activated by crewmember impact. Four prototypes were fabricated and tested, both statically and dynamically. The newly designed sticks were shown to withstand specified emergency loads, while separating at crash impact loads of 1/2 to 1/3 that of conventional sticks. Further, the energy-absorbing capacity of the stick prevents completion of stick delethalization motion for loads of very short duration and thus minimizes the risk of inadvertent separation.

PREFACE

This report was prepared by Simula Inc. under Contract DAAK51-82-C-0039 for the Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia, by Donald K. Eisentraut and Richard E. Zimmermann of Simula Inc., with contributions by Charles Whitaker and Christopher Bradney.

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INTRODUCTION

In a survivable helicopter accident, sufficient living space for the flight crew is maintained by the airframe structure. However, serious or fatal injuries may still occur if the occupants strike lethal objects during the crash. The restraint system with shoulder harness used by the crewmember reduces the potential strike envelope, and therefore decreases the possibility of serious injuries. One object which remains within this strike envelope is the cyclic control stick. The cyclic control stick is conventionally located on the floor between the crewmember's legs. Because of the loads that it may be required to support during emergency flight conditions, this control stick is made of relatively rigid metal tubing. The location and rigidity of the cyclic control stick increase the possibility that it may inflict injury to the head, neck, or upper chest of the occupant, even with a five-point restraint system in use, and the use of energy-absorbing seats has increased the hazard by bringing the upper body closer to the top of the control stick. Such injury potential has been noted in both the Bell AH-1S Cobra and the Sikorsky UH-60A Black Hawk helicopters currently in use.

The objectives of this program were to develop and analyze concepts for a crashworthy cyclic control stick and to design, fabricate, and test the most promising concept. Such a stick must separate close to the floor upon impact and be usable in both the AH-1S and UH-60A.

This report describes the efforts undertaken by Simula Inc. to achieve the above-stated objectives.

REQUIREMENTS

The crashworthy cyclic control stick program was constrained by certain requirements specified by the U.S. Army. These provided both physical and functional guidelines to be considered in the stick's development. The requirements stated that the crashworthy cyclic control stick designs would:

1. Provide 4 in. of vertical adjustment at the grip (±2 in. from nominal height).

2. Telescope or break away at a point no more than 4 in. above the pivot point during the crash sequence such that it poses a minimal hazard. The failure should occur in the form of a clean break, leaving no jagged or torn edges.

3. Not yield during normal and emergency handling o[illegible] he stick.

4. Accept the existing cyclic grips, as well as the [illegible]r cyclic control grip (Dwg 76-7477 U.S. Army Aviati[illegible] Materiel Command).

5. Provide room for at least 36 electrical conductors for the switches on the grip.

6. Be generic for use on existing and future helicopters with or without stroking seats.

7. Conform to the guidelines of USARTL-TR-79-22, "Aircraft Crash Survival Design Guide," and MIL-STD-1290, "Light Fixed- and Rotary-wing Aircraft Crashworthiness."

8. Meet control system loads of MIL-S-8698, "Structural Design Requirements, Helicopters."

Also required of this program was the fabrication and static and dynamic testing of four sticks of the selected design. The tests were to establish that the design functions as intended under emergency operational loads and under dynamic crash conditions, and to demonstrate that the potential of injury to the crewmember is reduced.

In addition to the above-stated performance criteria for the crashworthy stick, any design would obviously have to be just as airworthy as existing sticks. Both premature separation and looseness or yielding of the joint would be unacceptable. Therefore, a requirement for no degradation in airworthiness was presumed to have precedence over all of the specified requirements.

During the conduct of this program, assumptions were made concerning the relative priority of the Army criteria whenever all of them could not be satisfied by a particular design. For example, the design which was eventually developed and tested met all of the requirements except for the 4.0-in. separation height. However, study of the body and seat kinematics showed that the head and torso of the occupant would not strike the remaining portion of the stick. Therefore, the design was presumed to satisfy the intent of the requirements.

SELECTION CRITERIA

More than 100 different concepts for the crashworthy cyclic control stick were examined during the concept development phase of the program. It was found that these concepts could be grouped into five categories according to basic functional characteristics (see the Selected Concept Categories subsection). Each category was evaluated for its potential operational and functional performance relative to the other concepts. Eight criteria of importance to the feasibility of each category were:

- Effectiveness - a measure of how completely the danger of injury is removed. In some designs, actuation was effected by the pilot's body striking the cyclic control stick, while others were triggered by some alternate action. Also included in the effectiveness was the subsequent danger presented by the stub and/or stick remaining after collapse or separation.

- Reliability in flight - the reliability of the stick to maintain operational integrity without accidental release. The most important factor was that the crashworthy cyclic control stick not compromise airworthiness in the interest of delethalization. The stick must support emergency operational loads in accordance with MIL-S-8698.

- Reliability in a crash - the reliability of the cyclic control stick to perform its crashworthy function. Each design should function properly when actuated and be free from friction binding, incomplete separation, or any other hindrance to its delethalization.

- Controllability - proper feel and control operation. The pilot needs a "solid feel" to any cyclic control stick to maintain proficiency during flight operations. A crashworthy cyclic control stick should not alter the control characteristics, i.e., the stick should not feel loose, wobble, or spring in any direction.

- Maintainability - the ease of maintenance of the crashworthy control stick. A separating joint or cutting device must not require an inordinate amount of maintenance, though some additional maintenance over the simple tubular stick is inevitable.

- Commonality - the generic nature of the design for use in both helicopters considered under this contract. An emphasis was put on a maximum of common parts with a minimum of parts unique to each aircraft installation.

- Cost - initial and overall costs to implement this crashworthy cyclic control stick into the Army fleet. The design had to be simple enough to allow low-to-moderate fabrication and assembly costs and inexpensive operational maintenance.

- Compatibility - a measure of how well each design meets the requirements necessary for interface to the existing helicopter interiors. Each design must be capable of accommodating a wire cable bundle through its length, accepting two given grip styles, and mating with the two control linkage interfaces at the aircraft floors.

During the concept selection process, each of the concept categories and several subcategories were rated against the above criteria. Relative importance of the criteria was also considered, and the results were used to assist in the selection of the preferable crashworthy cyclic control stick configuration.

CONCEPT DEVELOPMENT AND EVALUATION

COCKPIT ENVIRONMENT

To help determine feasible approaches to the design of a crashworthy cyclic control stick, a study was made of the existing cyclic control sticks and their operating envelopes. The existing cyclic control sticks for the UH-60A Black Hawk (Sikorsky P/N 70400-01226-041) and AH-1S Cobra (Bell P/N 209-001-334-9) helicopters are shown in Figures 1 and 2. Tube sizes and materials differ (1.50-in.-diameter aluminum for the AH-1S, 1.125-in.-diameter steel for the UH-60A), as do the control grip interfaces. The AH-1S cyclic control stick has a long straight vertical section which could accommodate a vertical adjustment and telescoping or separating section. The UH-60A cyclic control stick does not.

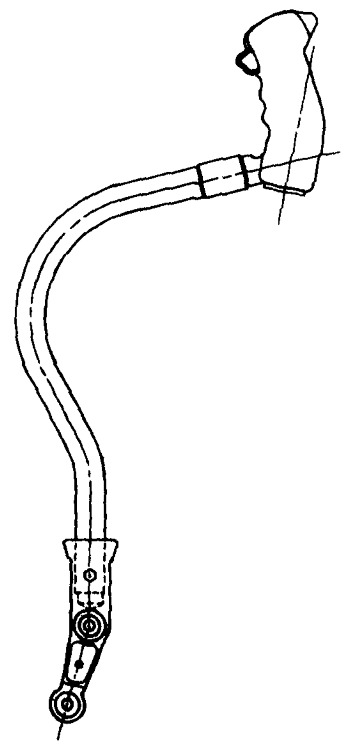

Figure 1. UH-60A cyclic control stick.

Another readily apparent difference is the control-stick-to-control-linkage interfaces. The AH-1S cyclic control stick disconnects at a point below the spherical sliding surfaces which are mounted just above floor level. The upper spherical surface,

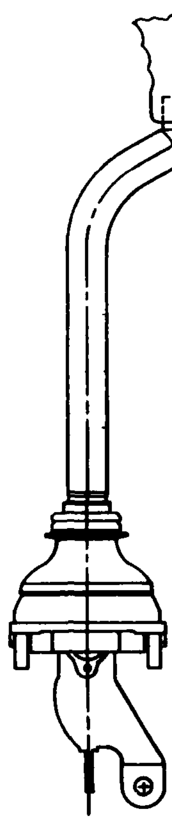

Figure 2. AH-1S cyclic control stick.

spring washers, and adjusting nuts are all attached to the control stick before it is mounted in the aircraft. The UH-60A cyclic control stick, on the other hand, plugs into a forged socket at the lower end with a one-bolt attachment.

There are also usage differences. The AH-1S uses the full cyclic control stick only for the pilot. The copilot/gunner cyclic control grip is mounted on a console beside the seat, whereas the UH-60A uses two identical cyclic control sticks for pilot and copilot in a side-by-side seating arrangement.

Figure 3 shows the operating envelope of the UH-60A cyclic control stick with the stick in the full-aft position. Apparent seat interference in the "full-up and forward" seat position is probably alleviated by compression of the seat cushion by the occupant and by a notch cut in the front center of the cushion for the crotch strap of the five-point harness. The dashed lines in this figure show the possible incorporation of a longer straight section of tube to accommodate the delethalizing mechanism and/or height adjustment mechanism.

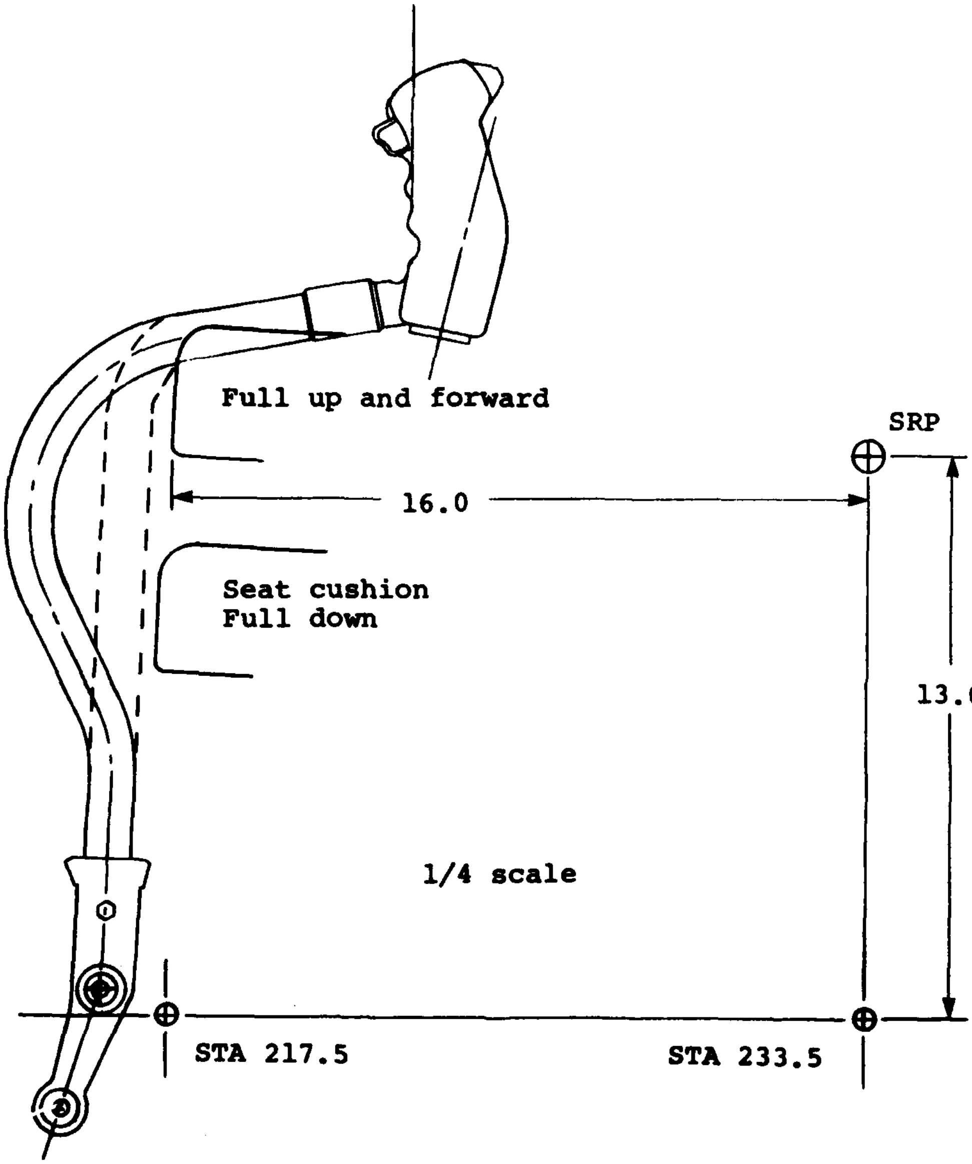

Figure 3. Stick/seat interface in the UH-60A.

Functional requirements per MIL-S-8698, "Structural Requirements, Helicopters," dictate that each of these cyclic control sticks must withstand emergency operational loads of a maximum of 200 lb at the top of the grip applied in the fore and aft directions within 30 degrees above or below a horizontal plane and 100 lb in the lateral direction without permanent deformation. All normal operational loads are well below these maximums.

CRASH ENVIRONMENT

Possible points of impact of the cyclic control stick by the pilot's body include the head, neck, and upper torso in a forward or downward deceleration, and the legs in a deceleration in any direction. Precise impact points are difficult to pinpoint due to the flexibility of the human body, its motion when subjected to various accelerations, and the position of the cyclic control stick which is dependent on forces received from the control linkage during an impact, due either to inertial or aerodynamic loads or structural distortions. However, review of dynamic test films with anthropomorphic dummies and computer simulations using Program SOM-LA gave some indication of the probable impact between the cyclic control stick and the occupant.

In a forward impact, a downward stroking energy-absorbing seat, such as those in the UH-60A, will not stroke. The seat currently used in the AH-1S cannot stroke, so the crewmembers on board these two helicopters would experience roughly the same motion under these circumstances. In a forward-pitched vertical drop, the energy-absorbing stroke of the seat in the UH-60A will take place. This will have the effect of increasing the cyclic control stick height relative to the seat, and will present the greatest danger of cyclic-stick-inflicted injury. In the AH-1S, the relative height does not change, lessening the cyclic control stick injury threat. With this in mind, the investigation was centered around the UH-60A Black Hawk helicopter because of its seat with stroking, energy-absorbing capability which results in the greater injury potential from the cyclic control stick.

To analyze the UH-60A crash performance, the computer program SOM-LA was used for computer simulations of both the 50th- and 95th-percentile crewmembers. For this simulation a 48-G vertical drop with 30-degree forward pitch angle and 50-ft/sec velocity change was used. This pulse is the same as the vertical dynamic test pulse of Reference 1, except that the 10-degree roll was not included in order to limit the simulation to two dimensions, thus representing the most probable cyclic stick impact conditions and simplifying the analysis. Occupants were restrained with a five-point restraint harness. The results are illustrated in Figure 4. The stick is shown as a reference only in the figure; the computer program does not account for impact with the stick and, thus, allows the occupant to pass through it.

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1. Desjardins, S. P., Laananen, D. H., et al., AIRCRAFT CRASH SURVIVAL DESIGN GUIDE, Simula Inc.; USARTL-TR-79-22A-E, Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia, December 1980, Volume I - ADA093784; Volume II - ADA082512; Volume III - ADA089104; Volume IV - ADA088441; and Volume V - ADA082513.

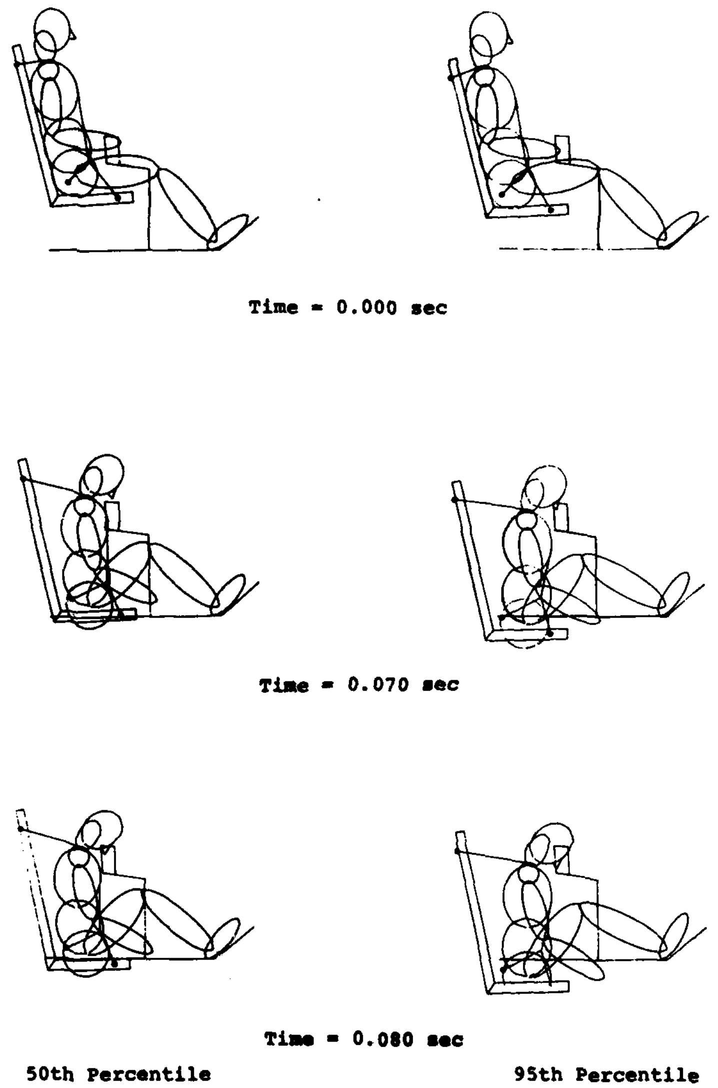

Figure 4. SOM-LA occupant model: UH-60A crewseat, 50-ft/sec, 48-G vertical drop with a 30-degree forward pitch (cyclic control full aft).

The velocity and angle of impact in the UH-60A based on the SOM-LA analyses are:

Occupant	Velocity	Angle*
50th-percentile	30 ft/sec	35°
95th-percentile	20 ft/sec	0°

*Angle is given aft of vertical; stick is in full-aft position.

The SOM-LA analyses also revealed the high probability that impact would occur about the head, in particular, the face.

A plot of the path of center of gravity of the head of each occupant is shown in Figure 5. This figure, based on the computer simulation described above, does not reflect interaction between the crewmember and the stick. They show the path that the c.g. of the head would follow with the occupant seated in the stroking seat bucket if he did not strike the stick. The points on the curve where impact would actually occur are marked with an x. Also, the curves do not reflect any discontinuity in the stroke of the seat. Head motion of the 50th-percentile occupant would resemble the full curve shown. The 95th-percentile occupant would experience a stoppage of the energy-absorbing seat stroke when the seat bucket reaches its downward limit. For the UH-60A helicopter, seat motion is halted when the seat bucket bottoms in a well which allows the seat to move approximately 5 in. below floor level. The 95th-percentile occupant would bottom in this seat well at a time corresponding to the head position 23 in. above the floor. The head would then follow a somewhat different path as the bucket stopped and greater accelerations were applied to the body and head. Although these curves correspond to no real situation in their entirety, they do show the maximum expected envelope of the head c.g. if stick impact does not occur.

Also worthy of note from Figure 5 is that the crewmembers' heads travel less than 12 in. downward after impact with the stick. The paths shown are a maximum excursion since they represent uninhibited movement. With an allowance for facial structure, a crewmember's head will stop its downward motion a minimum of 11 in. from the floor of the aircraft. This implies that the 4-in. maximum height of the remaining portion of the frangible stick from pivot point to the breaking point (Reference 1) is conservative, and a larger value may provide equivalent protection in this case, particularly if an energy-absorbing device, which would reduce head velocity, were used during stick separation.

High-speed films of dynamic seat tests with anthropomorphic dummies were reviewed to observe the motion of the head and upper torso. Seat types involved in these tests included the UH-60A and AH-64A crewseats. The sketches derived from some of these films are shown in Figures 6 and 7. The dummy test results are in approximate agreement with those of the SOM-LA simulation, as can be seen from Figure 7.

HUMAN TOLERANCES TO IMPACT

With the most probable point of impact now recognized as the head or face, human tolerances to blows in this area were examined. Literature was reviewed to ascertain impact tolerances for the head, face, and neck, but most of the published information reflected uncertainty in the values formulated. Information on the onset rates of the forces used and the severity of the fracture obtained was not available in all cases. Studies of the same

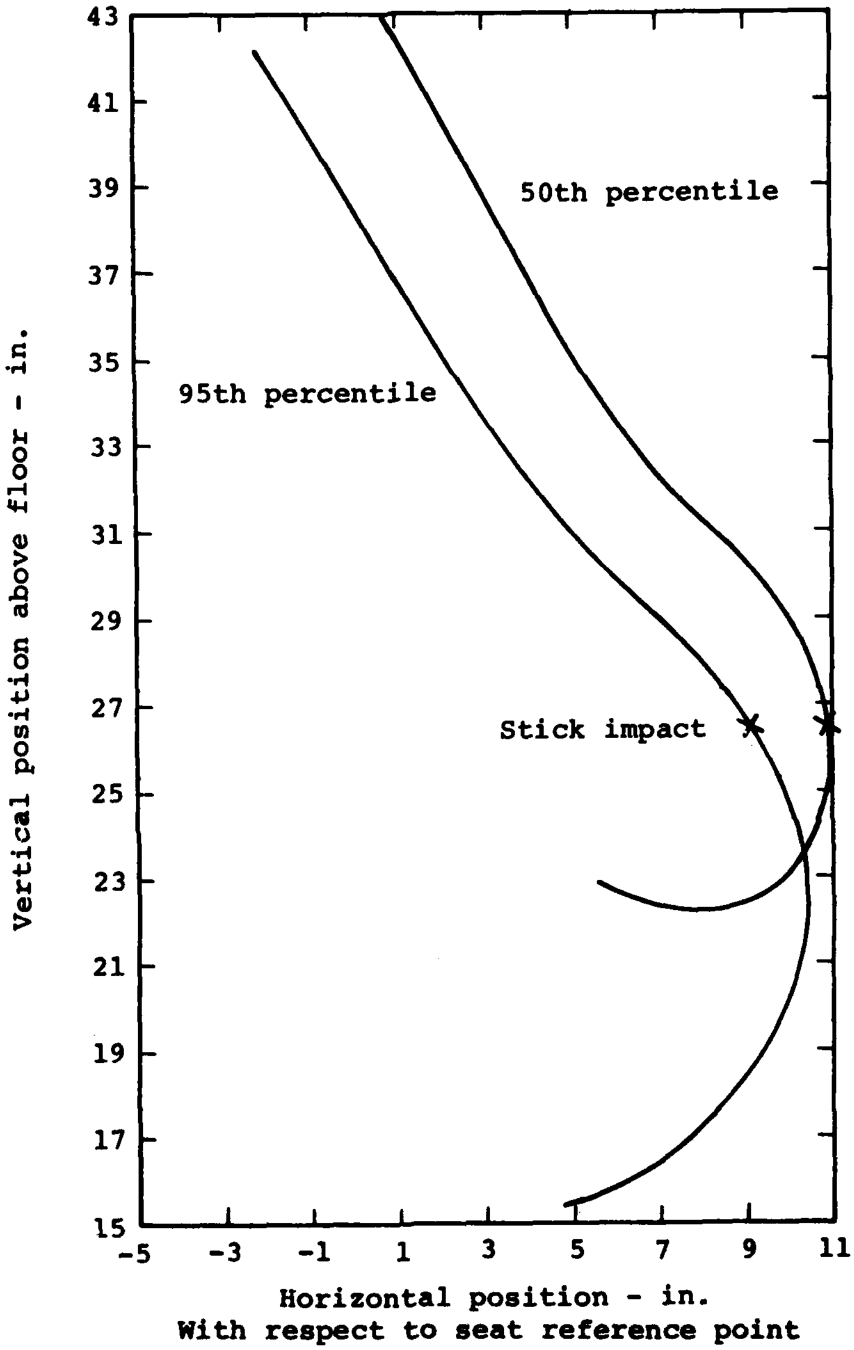

Figure 5. 50th- and 95th-percentile occupant head c.g. path during SOM-LA crash simulation.

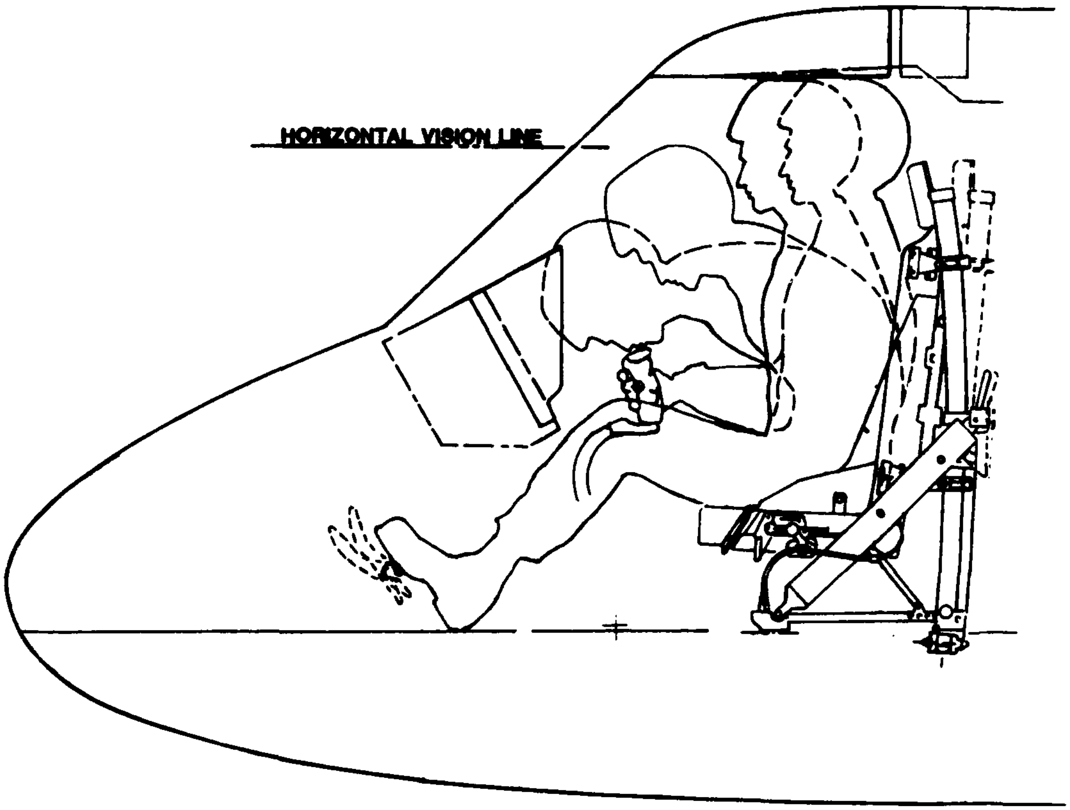

Figure 6. Strike envelope: UH-60A crewseat, 95th-percentile occupant, 50-ft/sec, 30G forward ($-G_x$) impact (cyclic control in neutral position).

skeletal structure reported varied results. Only one study was located which gave a concise compilation of results of numerous studies (Reference 2).

Table 1 contains cadaver frontal impact tolerances, derived from the literature, which were of immediate interest to this program. These impacts were inflicted using a 1-1/8-in.-diameter impactor with varying degrees of padding, a good approximation to the top of the cyclic control grip, which is approximately 1-in.^{2} in area.

The three sets of values for the frontal bone are from two different studies, but are somewhat in agreement. The first two sets

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2. Society of Automotive Engineers, "Human Tolerance to Impact Conditions as Related to Motor Vehicle Design," SAE Information Report J885, Society of Automotive Engineers, Warrendale, Pennsylvania, April 1980.

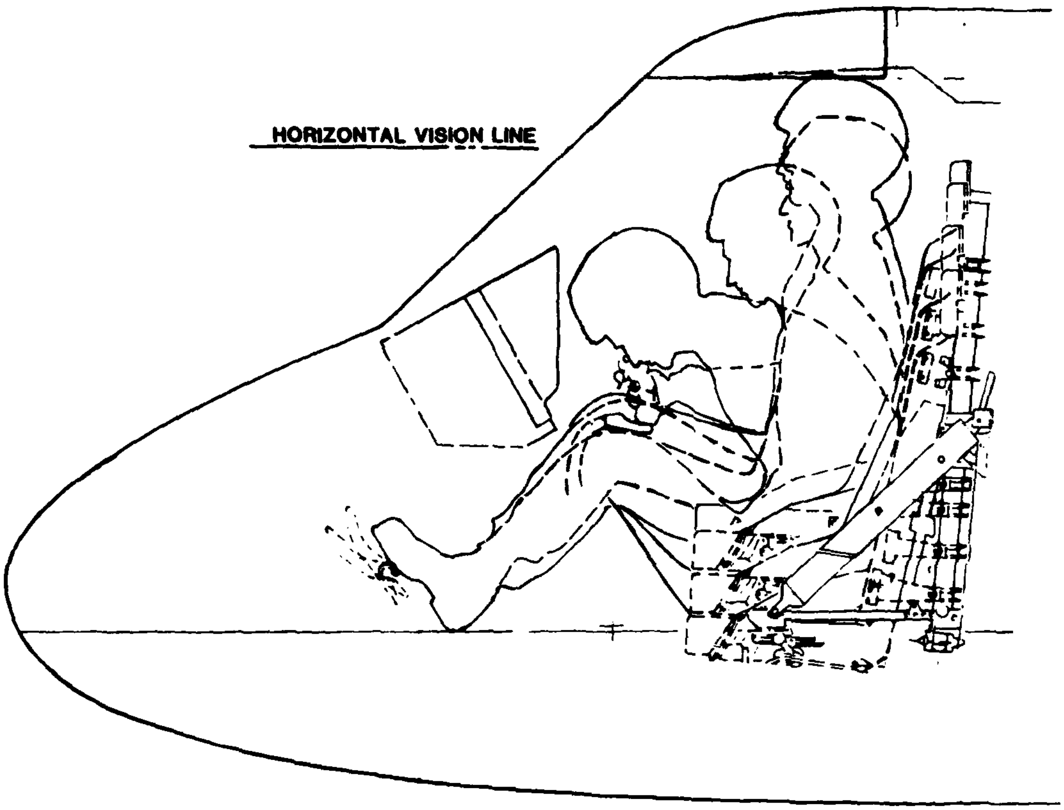


Figure 7. Strike envelope: UH-60A crewseat, 95th-percentile dummy, 42-ft/sec, 42-G vertical drop with 13 degrees forward pitch (cyclic control in neutral position).

of values are from the same study (Reference 3) and apply to fresh and embalmed cadavers, respectively. Impacts to the forehead with impactors under 2 in.^{2} inflict a depressed (cave-in) fracture rather than a linear fracture, which can cause mechanical impingement on the brain and allow entry of foreign bodies into the skull. A fracture of this type is considered a potentially extremely serious injury.

The cheekbone forces cited caused fracture of the bone from a frontal blow near the joint with the upper jaw bone, an area called a maxillary suture. Injury threat from these fractures could not be pinpointed beyond the conclusions of Reference 3 which recommended a level of 225 lb as that for "clinically significant fractures." This study also noted that the thickness of

---

3. Nahum, A. M., et al., "Impact Tolerance of the Skull and face," SAE Paper No. 680785, Twelfth Stapp Car Crash Conference, Society of Automotive Engineers, Warrendale, Pennsylvania, October 1968.

TABLE 1. HUMAN TOLERANCES TO IMPACT-FRACTURE FORCES IN THE HEAD AND NECK AREA

Bone	Mean (lb)	Range (lb)	Study (Reference)
Frontal (forehead)	1130	848-1600	3
	1390	980-1990	3
	1310	930-2220	4
Zygoma (cheek bone)	386	138-780	3
	374	208-640	4
	283	190-374	6
Maxilla (upper jaw)	258	140-445	4
Mandible (lower jaw)	697	425-925	4
Neck	Not given	90-100	5

overlying tissue played an important role. In Reference 6, paired tests were performed with the 1-1/8-in. diameter impactor on one side and a 2-9/16-in. diameter impactor on the other. Average fracture loads were 283 lb and 573 lb, respectively, demonstrating that the zygoma is also susceptible to concentrated loading.

The maxilla, the weakest of the facial bones, produced depressed and comminuted (small-pieced) fractures under the concentrated load. The severity of this injury was not estimated in the study cited, but a previous study by the same group cited a lower range of fracture values (175 to 210 lb) as a "clinical fracture tolerance."

4. Schneider, D. C., and Nahum, A. M., "Impact Studies of Facial Bones and Skull" SAE Paper No. 720965, Sixteenth Stapp Car Crash Conference, Society of Automotive Engineers, Warrendale, Pennsylvania, November 1972.

5. Gadd, C. W., Culver, C. C., and Nahum, A. M., "A Study of Responses and Tolerances of the Neck," SAE Paper No. 710856, Fifteenth Stapp Car Conference, Society of Automotive Engineers, Warrendale, Pennsylvania, November 1971.

6. Hodgson, V. R., "Tolerances of the Facial Bones to Impact," <u>American Journal of Anatomy</u>, Vol. 120, Jan 1967.

The shape and size of the mandible presents a wide range of impact possibilities. Values listed under the fracture forces of Table 1 are for a center frontal impact. Resulting fractures occurred at any of three locations: the cartilage joint with the skull, the rounded projection of the bone to this joint, or on the body of the bone itself.

The neck is an especially vulnerable area to a concentrated load. The fracture forces of Table 1 were obtained using unembalmed cadavers exposed to a drop weight with a 1-in.^{2} area. Dynamic loads of 90 to 100 lb produced marginal fractures of the thyroid or cricoid cartilage (Adam's apple cartilage and the cartilage ring immediately below, respectively). These fractures could be of a very serious nature, leading to total collapse of the larynx.

Because of the vulnerability of the head and neck to impact, both the Aircraft Crash Survival Design Guide (Reference 1) and MIL-STD-1290, "Light Fixed- and Rotary-Wing Aircraft Crashworthiness," guidelines recommend frangible or energy-absorbing objects and materials within the potential head strike envelope.

PASSIVE CONCEPTS

A passively crashworthy cyclic control stick could be produced by relocating the control stick out of the strike envelope or by enlarging and/or padding the impact area on the grip such that the distributed impact force could be tolerated.

Relocating the cyclic control stick to the side of the pilot would remove it from the strike envelope. Alternately, with an energy-absorbing seat, the stick could be attached to the seat near its original location. When the seat stroked, the stick would move down with the seat bucket and the probability of the occupant impacting it with significant relative velocity would be greatly reduced. This would only be feasible on an energy-absorbing seat, where the stroke of the seat reduces the strike envelope of the body by limiting the maximum acceleration.

These concepts were deleted due to major modifications necessary for this installation. They created a complex retrofit installation beyond the scope of this program.

A contractual requirement to utilize the existing cyclic control grips now in the Army inventory precluded redesign of the handgrip. Therefore, the impact area could not be enlarged or padded. After examining passive modes of cyclic control stick delethalization, it became apparent that no passive design was acceptable and some "active" mode was required, such as breaking, separating, or deflecting the cyclic control stick.

ACTIVE CONCEPTS

When considering an active concept for the crashworthy cyclic control stick, some method of starting the delethalization process had to be considered. The cyclic control stick had to maintain its rigidity until a crash, then break, separate, or deflect with little or no resistance. Two feasible triggering methods were devised to start this process: crewmember impact and alternate event.

Crewmember Impact Trigger

The most straightforward method of initiating delethalization was to use a strike of sufficient force to break or separate the stick. This impact must be within a tolerable range for the occupant, and above the force encountered during normal and emergency operation. "Structural Design Requirements, Helicopters," MIL-S-8698, requires that permanent deformation not occur for the test where:

> "A force of 200 lbs shall be applied to the top of the pilot's handgrip in the fore-and-aft-direction at any angle within 30° above or below horizontal. For lateral stick movement, a force of 100 lbs shall be applied to the top of the pilot's handgrip."

This requirement sets the minimum download trigger force at a value above 100 lb (the downward component of a 200-lb fore and aft load 30 degrees below the horizontal). A load above 100 lb would also be necessary to avoid inadvertent release. To maintain airworthiness by these requirements, an impact trigger force for the crashworthy cyclic control stick must be slightly above that which would afford the best protection to the neck area. As shown in Table 1, neck injury may occur at 90 to 100 lb. Therefore, neck injury cannot be precluded due to conflicting requirements. To stay within a safe range for facial or head impact, a range of values from slightly above 100 lb up to 160 lb is reasonable, as is also shown in Table 1. Therefore, this range was selected for the design of the sticks.

The occupant impact used to trigger the stick may also be of one of two forms. In one form, the pilot impacts the stick with a given amount of force to cause complete release of the stick. Alternately, a stick could be devised in which the required separation force must be maintained through a set distance. In this way some of the kinetic energy of the pilot's motion could be absorbed by the deflecting structure of an energy absorber. This feature would also give better resistance to inadvertent release. An accidental release is less likely when the impact force is required to move through a distance rather than when the application of the force and the release occurs simultaneously.

Alternate Event Trigger

A second triggering mechanism involves the use of an external power source with an external crash-sensing system. Pilot impact as a trigger for this external power source would be impractical since a time delay between impact and stick delethalization cannot be tolerated.

Stroking of the energy-absorbing seat or excessive pressure from hydraulic landing gear could be used to start the cyclic stick delethalization process; however, these approaches were judged not feasible for this program since one of the helicopters involved did not possess hydraulic landing gear or energy-absorbing seats.

One feasible approach to the alternate event trigger was the use of an electronic crash sensor. For any electronic crash-sensing device, though, safeguards must be used to prevent premature activation. One such safeguard might be a sensor's ability to distinguish the accelerations of a crash situation from those of hard landings, unusual vibrations, ballistic impact, bomb blast, etc. This could be done through the use of a time-acceleration integrator to detect the sustained accelerations of a crash.

SELECTED CONCEPT CATEGORIES

All concepts developed for a crashworthy cyclic control stick were classified into five categories:

1. Deforming
2. Tube-cutting
3. Telescoping
4. Collapsing
5. Separating

The following paragraphs present examples of each category and describe some of their merits and limitations.

Deforming Designs

Deforming designs for the crashworthy cyclic control stick include ideas for frangible, curved bendable, and column collapsible sticks. These designs would be fabricated of a material or with a weakened area which would deform or break under the desired crash impact load.

This simple approach was not feasible for this program due to the magnitude of the required emergency operational loads compared to the desired breakaway loads. No stick designed for deformation

or frangibility could withstand the bending moments imposed by the specified emergency operational loads.

Tube-Cutting Designs

A tube-cutting design is one in which the tube that makes up the crashworthy cyclic control stick is one continuous piece until a cutting mechanism is activated and the tube severed. Two types of tube-cutting designs were considered: mechanical cutters and pyrotechnic cutters.

Conventional mechanical tube cutters require multiple revolutions with progressive tightening of the cutter to completely separate the tube. Any attempt to adopt this type of mechanism would be unduly complex.

A guillotine-type cutter was also considered, as was the mechanical cutter shown in Figure 8. This device has four cutting surfaces set into slots in the cyclic control stick tube. The cutting surfaces would be fixed to a common ring around the stick. Inside the tube, a die would be positioned on either side of the cutter. The cutter and dies would then act as a shear as the ring rotated about the stick. When the cutter ring was rotated one-quarter turn, the stick would be sheared in two planes, each adjacent to a die. This shearing would take approximately 10 to 15 percent of the force necessary to shear the entire tube at once since only a small percentage of the tube material would have to be sheared at a time.

This reduced force, however, is still beyond any amount which could be generated by a "safe" pilot impact on the cyclic stick. Therefore, this or any other mechanical tube-cutting device would require an external power source, such as a small hydraulic cylinder or a gas generator activated by an alternate event trigger.

A pyrotechnic-cutter design is shown in Figure 9. This device consists of a shaped explosive charge surrounded by a blast-proof housing attached to the tube. When fired, the charge severs the tube and causes it to be displaced. During a crash, detonation would best be performed electrically, before the pilot came in contact with the stick, thus making an alternate event trigger desirable for this cutting mechanism as well.

Both of these cutting concepts offer some positive features. First, the cyclic control stick remains in one piece until the cutting mechanism is activated. This gives the controls a "solid" feel with no joints or hinges to loosen. A solid stick will not be released accidentally by rough or improper handling. Next, when the stick is cut, the cut can be made close to the floor with little remaining stub, and severing the stick before the occupant comes into contact with it removes the hazard of the occupant's initial contact with a rigid stick.

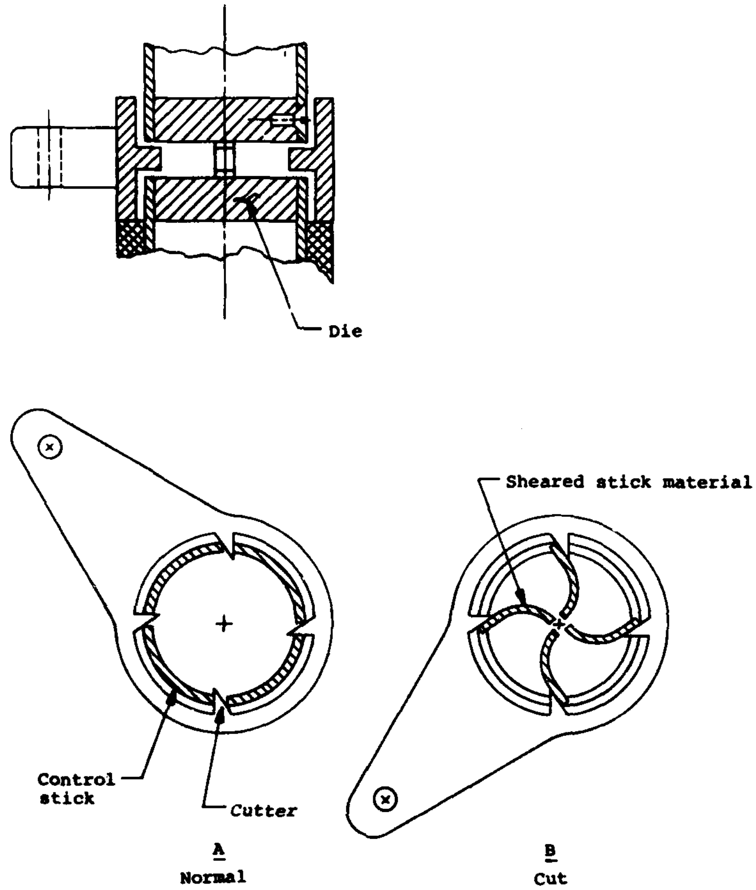


Figure 8. Mechanical cutter.

However, without incorporating a system to dislodge the stick from its original position, the severed stick can become wedged between the impacting occupant and the stub or floor and exert as great a force as if it had not separated. Also, two separate systems are involved: 1) a crash sensor or alternate event trigger, and 2) either a power source for the mechanical cutter or a detonating system for the shaped-charge cutter. Each system increases the complexity of the design, increases maintenance, and increases the chance for malfunction.

The concept of the tube-cutting crashworthy cyclic control stick design was highly rated when compared with subsequent concepts against the selection criteria, but was judged to be beyond the scope of this design program due to the complexities of the multiple systems involved and possible retrofit problems. Installation and maintenance costs could also be prohibitive.

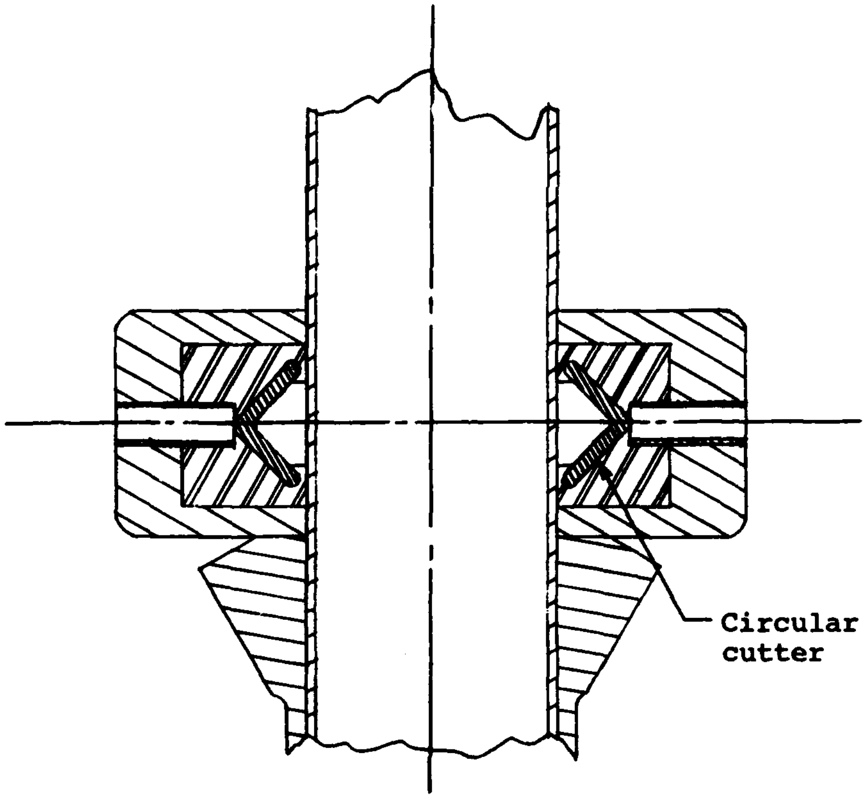


Figure 9. Pyrotechnic cutter.

Telescoping Designs

A telescoping cyclic control stick could perhaps present the simplest approach to delethalizing the stick. Such a device would consist of two or more concentric, overlapping tubes. When the occupant strikes the cyclic control grip during a crash, the upper, inner segment would slide inside the outer segment. A two-segment telescoping design is shown in Figure 10 (dimensions are shown typical to the UH-60A adaptation).

The telescoping design has several favorable aspects, the first being its simplicity. The only mechanisms necessary for the configuration are a friction collar or similar device to provide the height adjustment and telescoping resistance, and a torsional locking device to keep the concentric tubes from rotating during normal flight. This design also has the benefit of maintaining flyability even after inadvertent release.

During a crash impact release, the occupant would exert a force within the "safe" limits (defined in the Crewmember Impact Trigger section) over a short distance until the upper stick segment is freed within the lower segment.

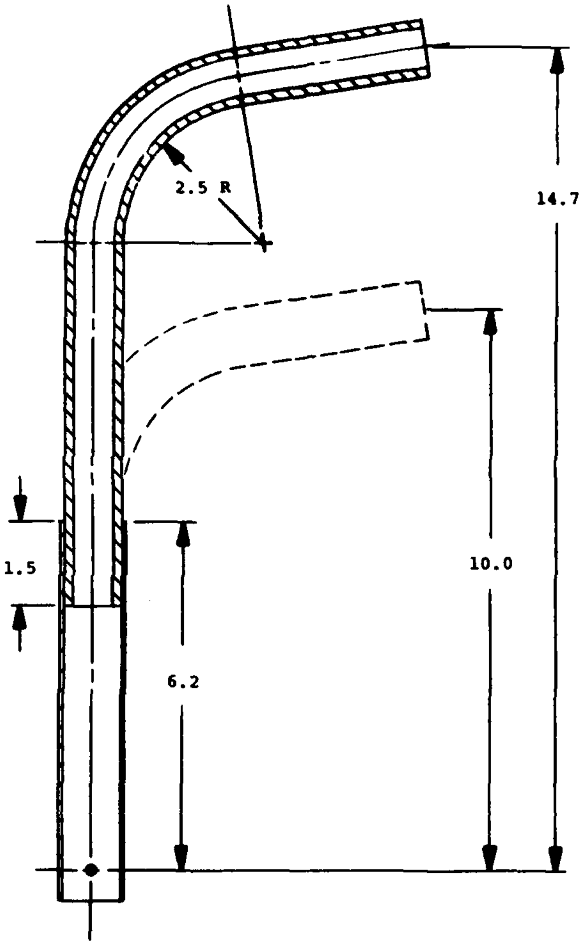


Figure 10. Two-segment telescoping stick.

Friction plays a large part in the operation of the telescoping mechanism. Simple sliding tubes would not operate smoothly due to the large moment placed on the sliding joint by impact on the grip, which is offset to the rear of the centerline of the stick. This moment would induce large frictional forces between the tubes. Several configurations of joints were considered which would reduce this frictional force. Each added complexity or instability to the design. Roller bearings between the sections added significant complexity and bulk. A nylon or Teflon sleeve bearing provided reduced friction loads, but would still be insufficient to allow the required low-friction telescoping under the bending moments applied.

Another disadvantage of the telescoping design is its incompatibility with the required wire bundle. This wire bundle would have to be contained within the tube from the grip to a point near the

floor. When the tubes attempt to telescope, the 36-wire bundle would tend to gather and probably jam, or at least inhibit, the tube sections.

The primary disadvantage of the telescoping design is its limited delethalizing capability. As shown in Figure 10, a two-segmented telescoping cyclic control stick would retract an inadequate amount to be effective. A minimum overlap of 1.5 in. for each tube section was required to withstand the emergency operational loads and to contain an anti-friction device. When an adjustment mechanism is incorporated, the effective stroke decreases, especially at the lower positions.

The addition of a third segment to the tube would add a minimal amount of stroke at the penalty of added complexity and loss of rigidity.

Collapsing Designs

A collapsing cyclic control stick design contains one or more hinged joints to allow the stick to fold or swing clear during a crash impact. Figure 11 shows a collapsing stick with an energy absorber supporting the grip in flight operation position. If the control grip of this stick design were struck downward, as in a crash situation, the hinged pivot would allow the grip to travel downward a short distance with little resistance. For the impacts predicted by computer simulation, this distance would not be adequate to prevent serious injury.

To obtain a better stroke for delethalization, the collapsing stick could incorporate a telescoping feature for height adjustment and additional stroke following collapse. Figure 12 shows such a system. Though not able to comply fully with the recommended separation height as stated by the Aircraft Crash Survival Design Guide (Reference 1), this design could be reasonably effective in lessening the severity of the occupant impact with the cyclic control stick.

In the Figure 12 design, the upper collapsing mechanism would be released when sufficient down load was applied to the control grip to break a shear pin. The grip and its horizontal arm would swing down as in the simple collapsing version. When the upper portion collapsed to a predetermined point, the adjustment/telescoping portion would be released, allowing the collapsed arm and a portion of the upright tube to descend. The arrangement would be sufficient for a head or neck impact on the grip, but would also leave a large "stub" which could cause subsequent injuries.

One of the largest limitations on the collapsing cyclic control stick is the proximity of the emergency operational loads to the crash impact loads. The moments expected on the pivot point by each of these forces are nearly equal. Also, in the case of the AH-1S Cobra, the horizontal arm is very short, which prohibits the use of the design shown in Figure 12. The design shown in

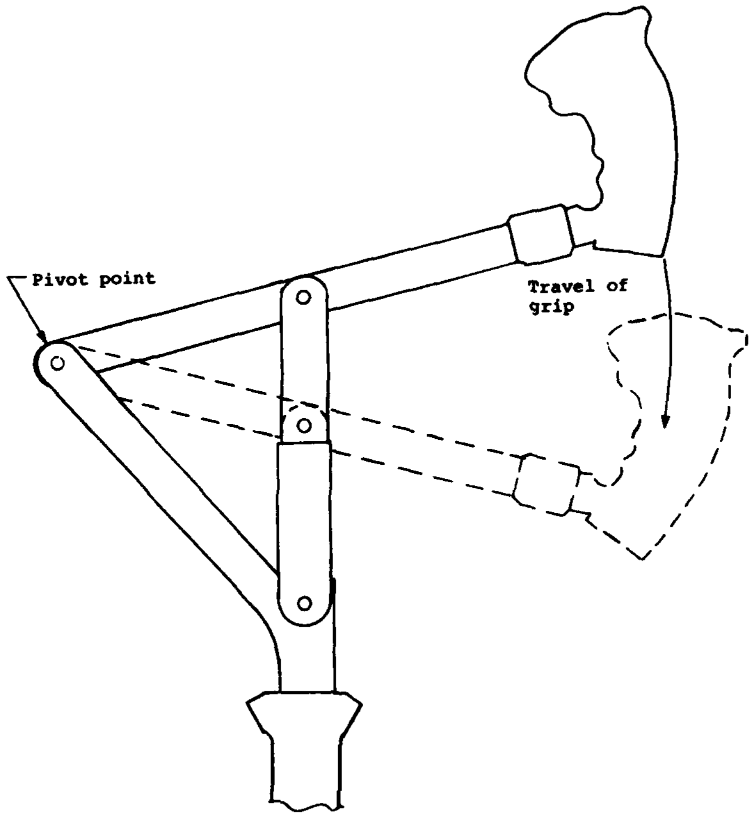


Figure 11. Collapsing stick.

Figure 11 is not suitable for use in the AH-1S because of interference with the instrument panel. So, from commonality considerations, the collapsing cyclic control stick is not acceptable for this program.

Separating Designs

All of the designs considered under the separating designs category operate on the principle that, when they are struck by an occupant during a crash, the force exerted on the stick by this impact releases a joint between two sections of the stick.

Three subcategories of separating designs were considered:

1. Clamp joints
2. Sleeve joints
3. Slip joints

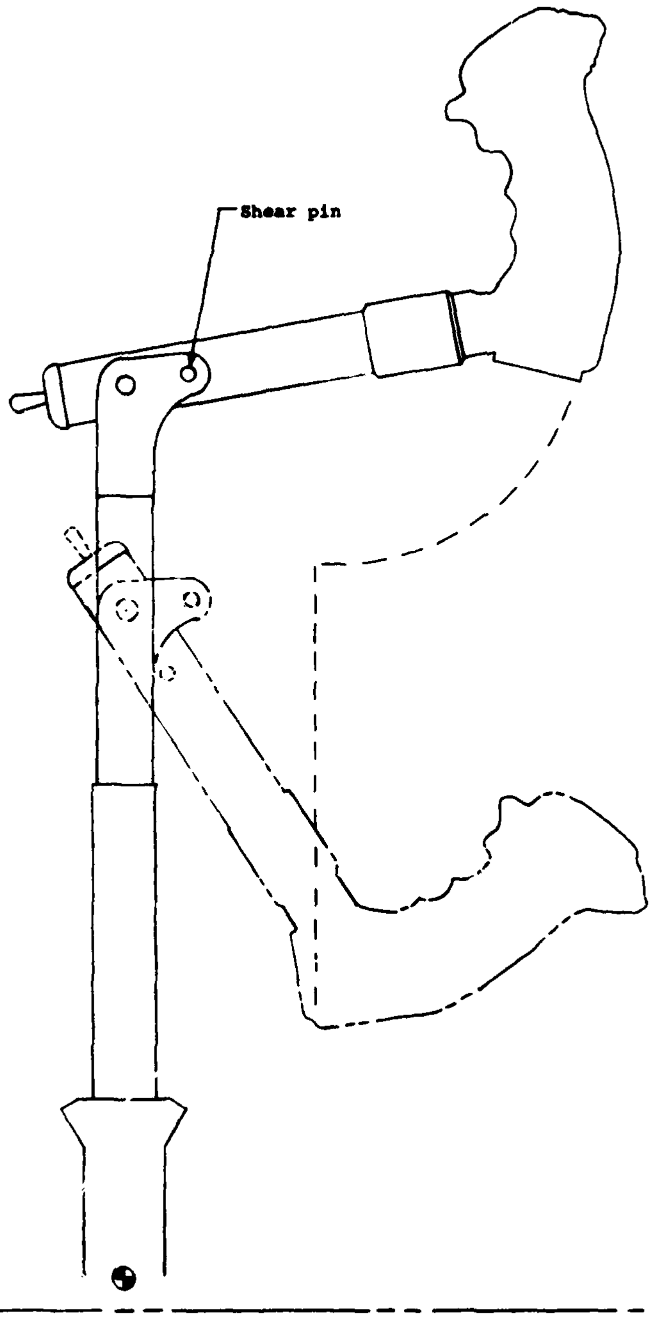


Figure 12. Collapsing (and telescoping) stick.

Clamp Joint. A clamped configuration consists of a two-piece tube with a clamping device rigidly attaching the two pieces. Occupant impact with the stick during a crash sequence causes the stick to telescope a short distance, releasing the clamp and allowing the stick to deflect clear.

The clamping may take place internally or externally. In an external clamp joint concept (shown in Figure 13), the external clamp is released from the joint by a telescoping upper portion of the stick.

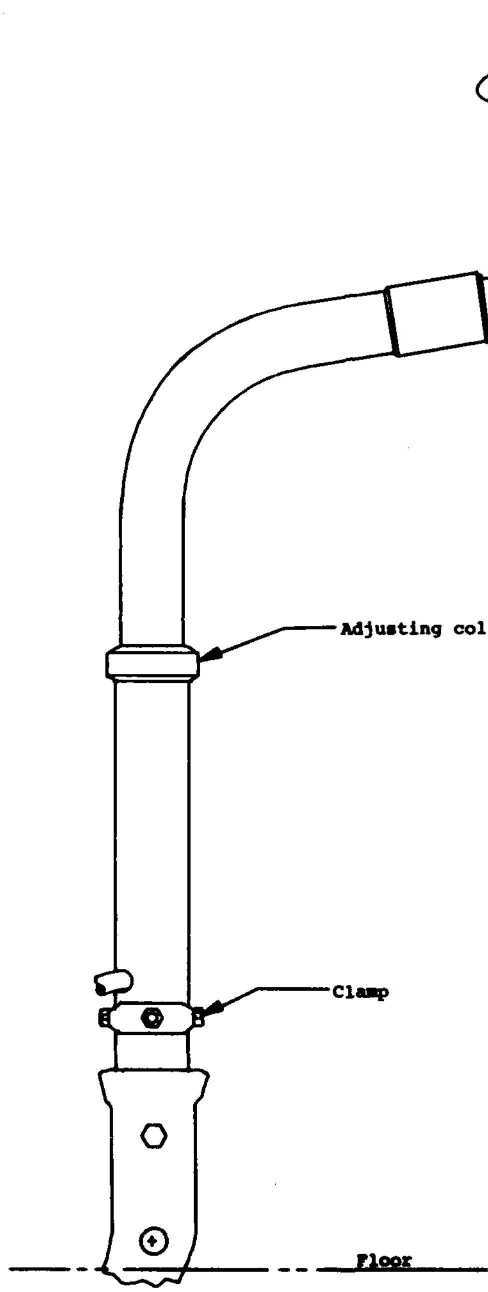


Figure 13. Clamp-jointed separating stick.

A collar over the telescoping upper section of the stick would be used to adjust the height. This upper collar would also serve as a friction lock of the telescoping section. The frictional force exerted by the collar would have to be overcome with a crash impact. This configuration would require a torsional lock for each segment of the stick.

Several methods of clamp retention were studied. One, shown in Figure 14, is a segmented internal ring with a tapered sleeve forced in to hold the segments in position on flanges at each end of the tube sections. The telescoping upper portion of the stick would knock the tapered sleeve out of its locking position and allow the clamp and tubes to separate.

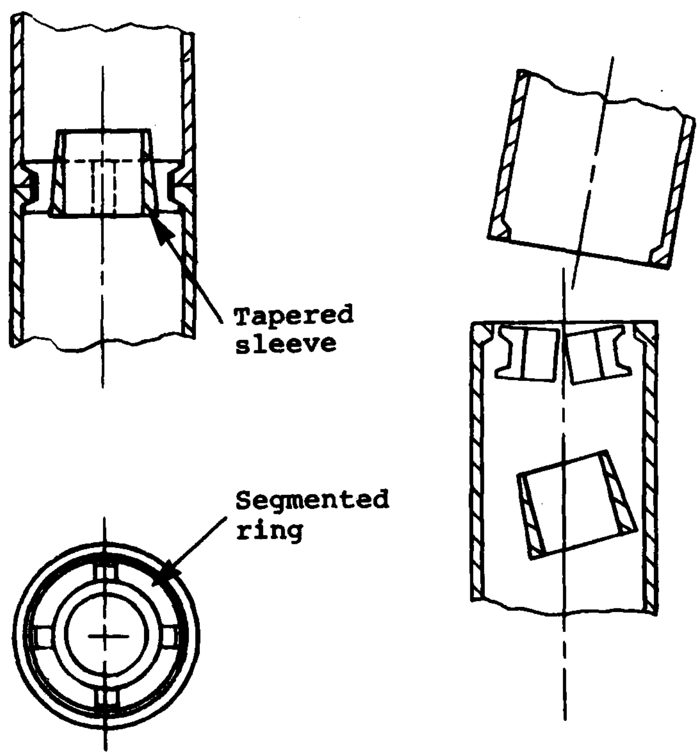
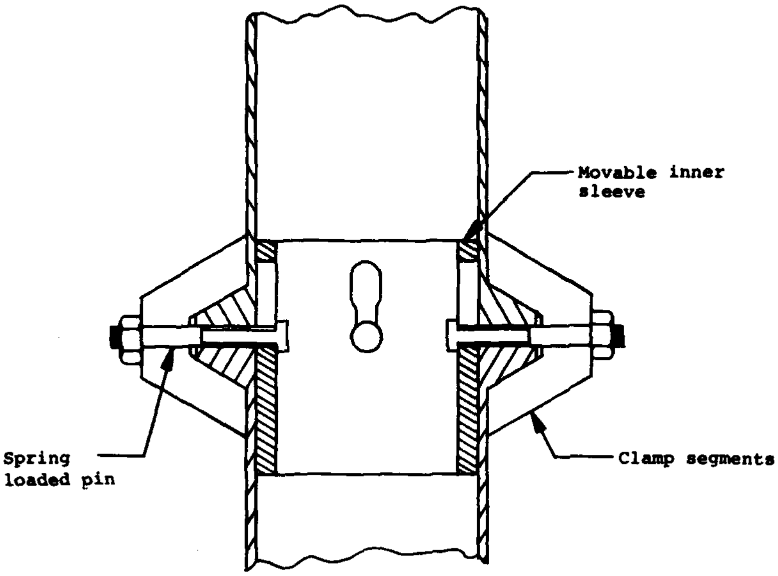
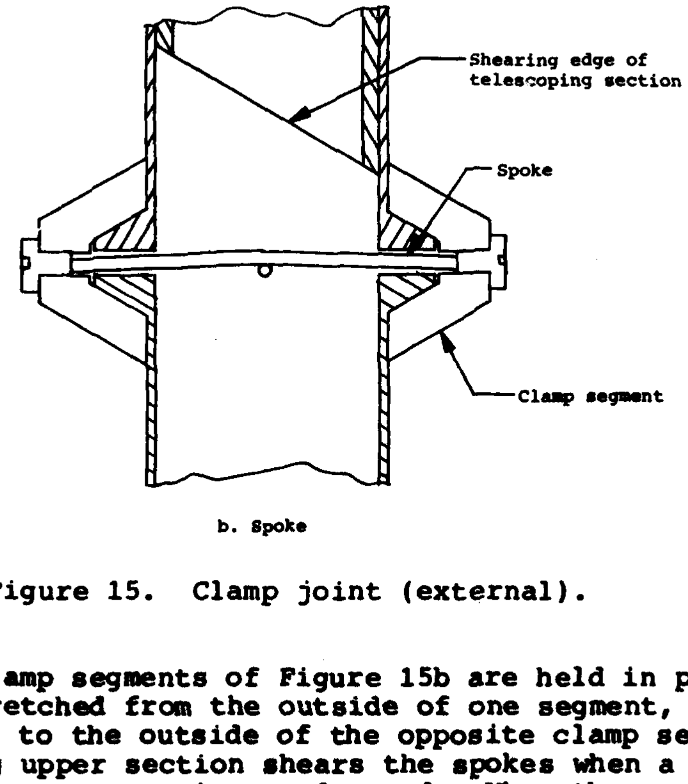


Figure 14. Clamp joint (internal).

External clamps are shown in Figure 15. The clamp segments in Figure 15a are held in place by spring-loaded pins which are stretched from the outside of the joint to a slot in the movable inner sleeve. When this sleeve is forced downward by the telescoping section, the pins are released from the slot and retract to allow the clamp segments to separate.



a. Spring-loaded pin



b. Spoke

Figure 15. Clamp joint (external).

The external clamp segments of Figure 15b are held in place by wire spokes stretched from the outside of one segment, through the tube joint, to the outside of the opposite clamp segment. The telescoping upper section shears the spokes when a crash impact causes the upper section to descend. When the spokes are

severed, the clamp segments are freed and the tube joint can separate. For this clamp method, no suitable material for the spokes could be found to withstand the tensile load required to keep the clamp in place and shear easily under the expected crash load on the stick.

Though the clamp concept presents a compact design with a minimum of stub remaining after separation, several factors weigh heavily against it. With a telescoping section comes the problem of friction during operation. The telescoping section must be a tight fit throughout the height adjustment range, the same distance it must telescope without any binding during a crash impact. In order to maintain rigidity and strength at the clamp joint, tight tolerances must be held to assure a good clamp grip on the tube ends. This requirement leads to high machining costs for all parts involved in the clamp connection. Most important is the possibility of incomplete separation. Should all the clamp pieces separate as planned, there is still a possibility of the loose stick becoming wedged between the pilot and the tube stub.

Sleeve Joint. Another concept similar to the clamp joint is the sleeve joint shown in Figure 16. This concept uses a sleeve to maintain alignment and rigidity of the tube sections. The figure shows an internal sleeve arrangement. The telescoping upper portion of the stick moves downward upon pilot impact. As the openings in the telescoping section match those of the spring-loaded balls used to keep the sleeve in place, the balls are released into the tube. This allows the sleeve to move downward with the help of the lower spring. The tube joint is then free to separate.

Sleeve joints presented much the same advantages and disadvantages as clamp joints. The compact design with a short remaining stub was possible, but the friction and wedging problems would still be present. Also, a momentary pause in the deflection of the control stick is required for the spring-loaded sleeve to release the joint. This discontinuity in the motion could lead to a large resistive force against the pilot, thereby reducing the delethalization capability of the stick.

Slip Joint. The third type of separating joint examined was the offset slip joint. This crashworthy cyclic control stick concept uses a slip joint between two sections of overlapping tubing, with their centerlines offset to accommodate the joint (Figure 17). Some mechanism must be used between the tubes to maintain rigidity until separation is desired. The mechanism could range from a simple shear pin (as shown in Figure 17) to an energy absorber with a stroking threshold within the desired separation force range.

This arrangement was rated highest of the noncutting designs when weighed against the selection criteria. The complexity of the design is reduced since there is only one moving joint. The upper tube can contain a height adjustment mechanism independent of the slip joint. The wire bundle from the grip can easily be

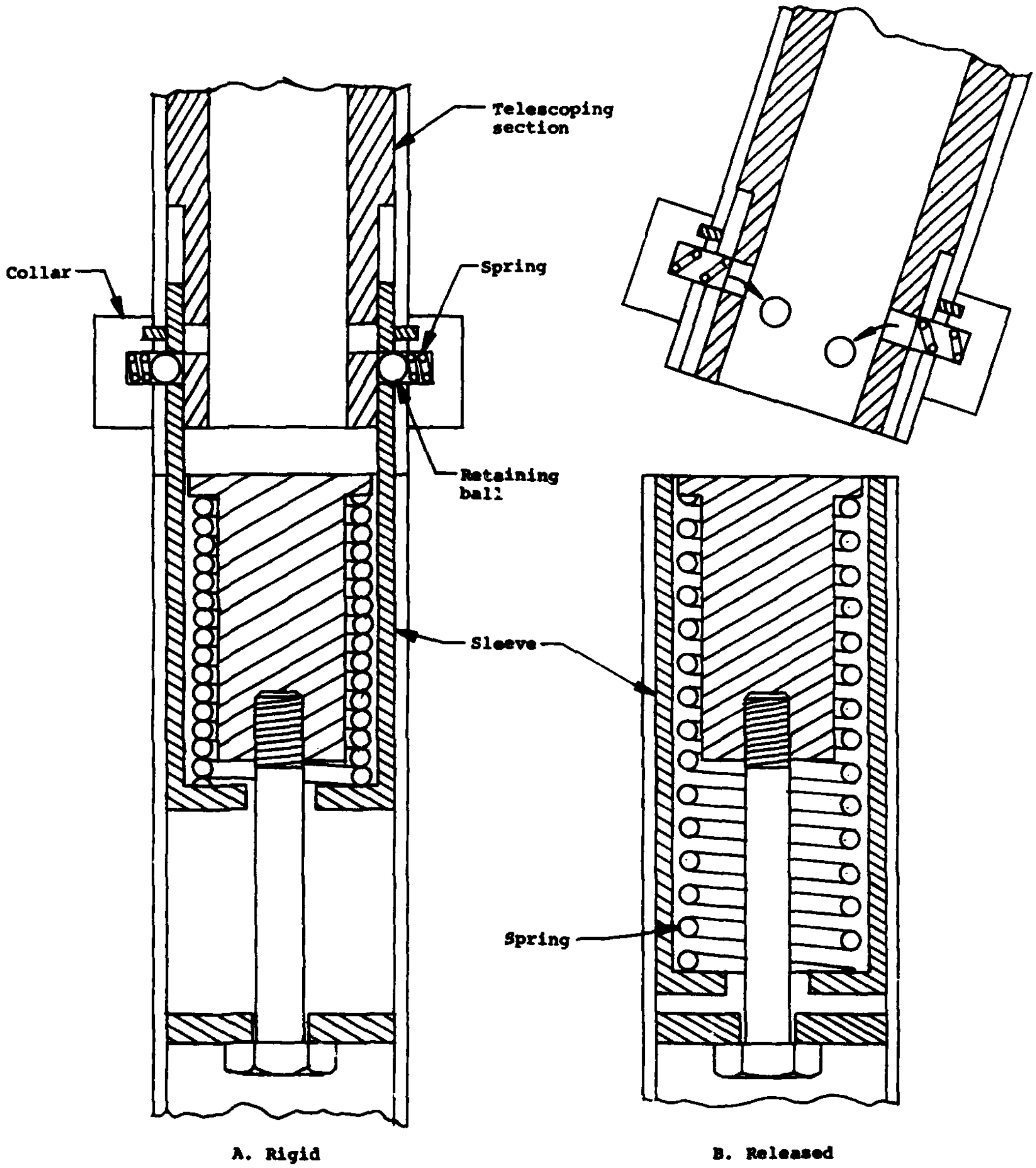


Figure 16. Sleeve joint (internal).

routed out the open bottom of the offset tube. Only enough space for clearance of the released joint is needed below the joint, thus allowing a minimum of stub to remain.

A distinct advantage of this design versus the other separating joints is that the major obstacle of delethalization is eliminated. Wedging of the separated stick between the pilot and the

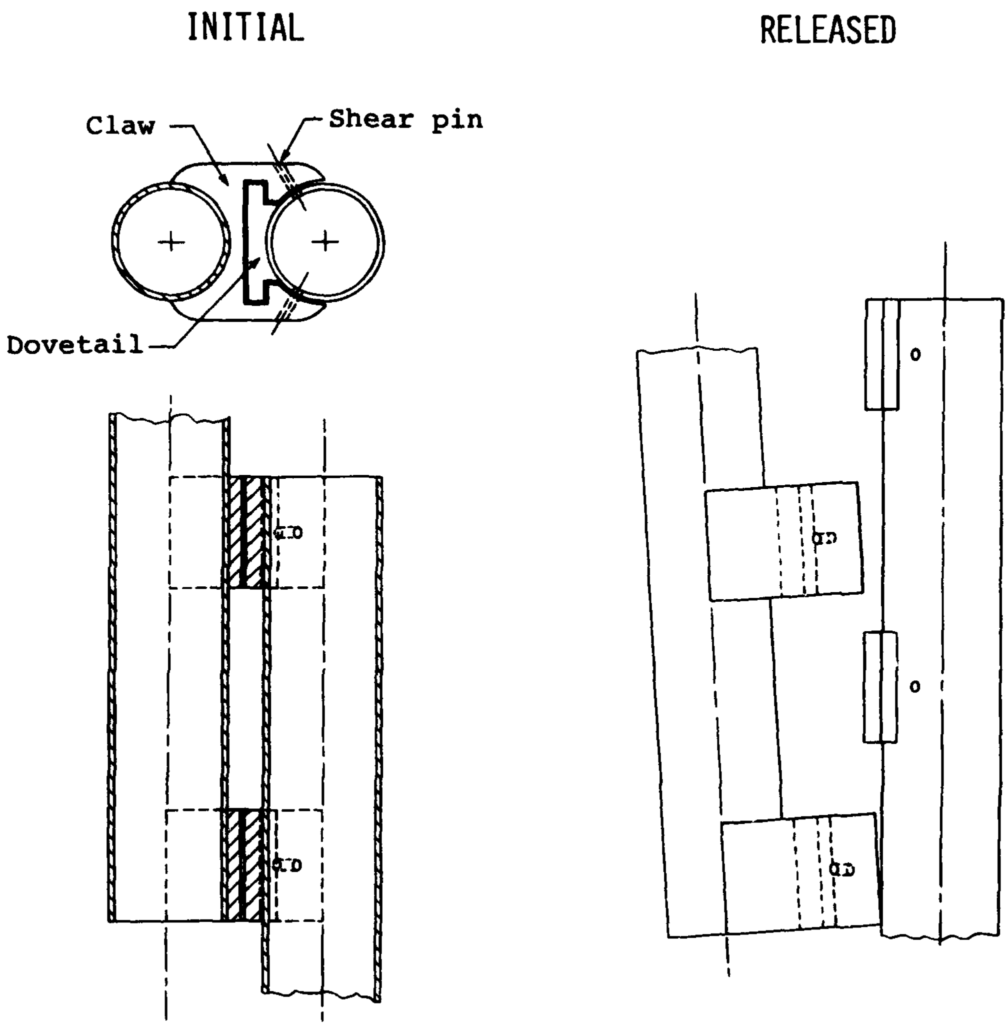
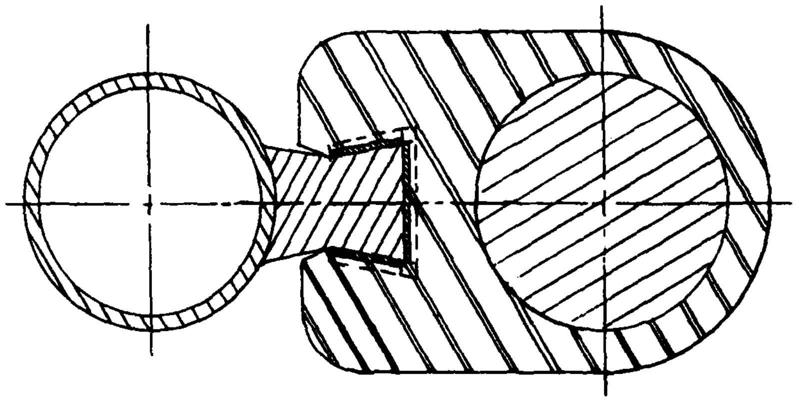


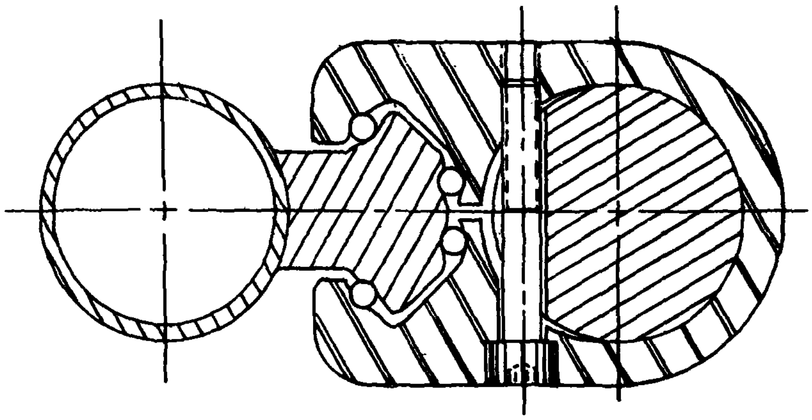
Figure 17. Slip joint.

remaining stub can be prevented, while still maintaining a one-axis release mechanism to meet the operational requirements of MIL-S-8698 in the fore, aft, and lateral directions.

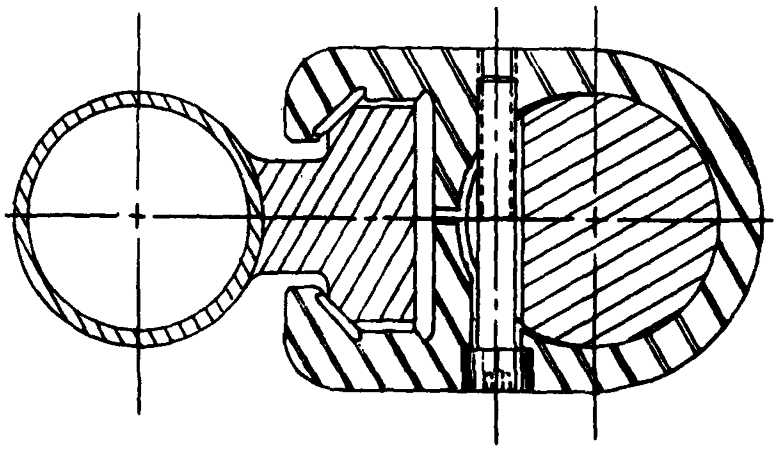
A dovetail and claw type slip joint was judged best able to withstand these operational loads. However, a simple metal-to-metal joint, as shown in Figure 17, would have a frictional resistance of large magnitude. To alleviate this problem, several refinements of the dovetail and claw joint were studied. Figure 18 shows three of these alternate designs: the wedge joint, the ball roller joint, and the needle roller joint.



A. Wedges



B. Ball rollers



C. Needle rollers

Figure 18. Slip joint concepts.

The wedge joint uses three tapered wedges on the surfaces of the dovetail. These wedges are pressed into place to make the joint rigid. Once a small relative motion occurs between the dovetail and claw, the wedges would displace slightly causing a clearance to develop. The frictional resistance would then be decreased, but with the downward force on the cyclic control stick grip causing the large moment on the joint, the frictional force might reappear as the wedges were pinched between the faces of the dovetail and claw.

The same basic joint adapted to ball rollers was also considered. This feature would eliminate any resistance, except rolling resistance of the balls, for the length of the joint until complete separation. An improvement on this idea was the use of needle rollers on the three surfaces. The cylindrical needle rollers would provide broader contact areas than the ball rollers and would better tolerate the compressive forces resulting from operational loads applied to the grip. When the joint was released, these needle rollers would be freed at low velocity, presenting no hazard and requiring no additional containment.

RECOMMENDED DESIGNS

Each design was rated against the selection criteria and relative to each other. Cutting designs were eliminated, and the highest rated noncutting design was the slip joint separating concept. As a result of this rating, four designs of the concept were prepared for evaluation at a briefing at the U.S. Army Applied Technology Laboratory. The two most promising designs are presented in Figures 19 and 20.

The first slip joint design (Figure 19) utilized a latch to keep the slip joint in place during normal operation. Height adjustment would be accommodated by the upper tube sliding inside the telescoping tube with a pin to select an incremental height change. Resistance to separation would be provided by a cylindrical energy absorber surrounding the telescoping tube.

When the occupant strikes the cyclic control grip in a crash, the telescoping tube would descend through the slip joint fitting. As this tube descended, it would crush the energy absorber against the slip joint fitting causing the diagonal arm to retract the latch until it cleared the line of separation of the slip joint. The slip joint would then separate, freeing the stick.

The second design (Figure 20) uses only the energy absorber to keep the slip joint in place. The bottom of the cylindrical energy absorber rests on a fork which is attached to the stationary portion of the slip joint. The movable portion of the slip joint is rigidly attached to the upper portion of the stick. Height adjustment is similar to the first design.

In order for the upper portion of the cyclic control stick to separate, it must crush the energy absorber as it descends with the

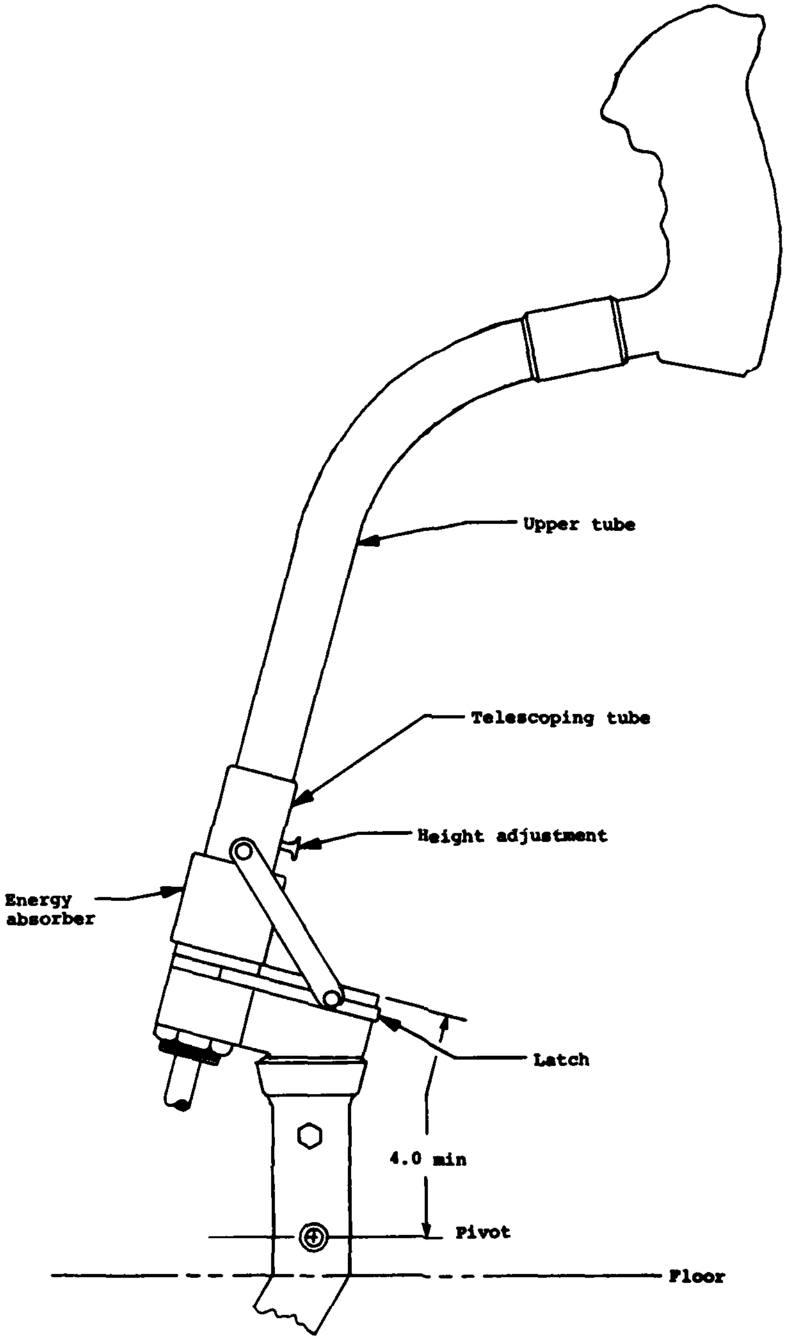


Figure 19. Slip joint with latch desig...

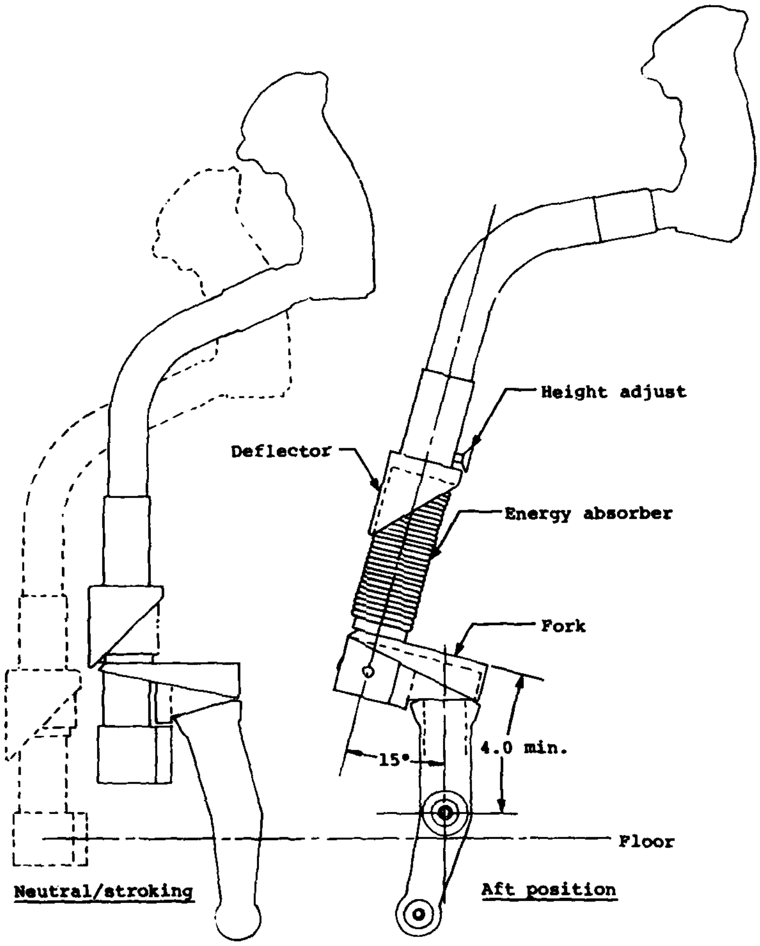


Figure 20. Slip joint (without latch) design.

force of the impact thereby freeing the slip joint. To dislodge the stick from this position, a deflector is attached to the moving tube which contacts the edge of the fork as the energy absorber continues to crush. The deflector guides the loose portion of the stick forward, off the fork, to prevent wedging of the stick between the pilot and the stationary fork.

The Applied Technology Laboratory selected the second design for development because of its simple operation, compact construction, and freedom from friction and binding. The latch design incorporated more moving parts with a possibility of friction or binding in either the telescoping mechanism or the sliding latch. With a proper energy absorber, the nonlatching design can be as reliable against inadvertent release as the latching design.

SELECTED DESIGN

The outline of the final crashworthy cyclic control stick developed for this program is shown in Figure 21 overlaying the outline of the existing UH-60A Black Hawk cyclic stick. Several adjustments and changes to the concept of Figure 20 were required to reach the final configuration. Most noticeable is the distance from the pivot point to the top of the remaining stub.

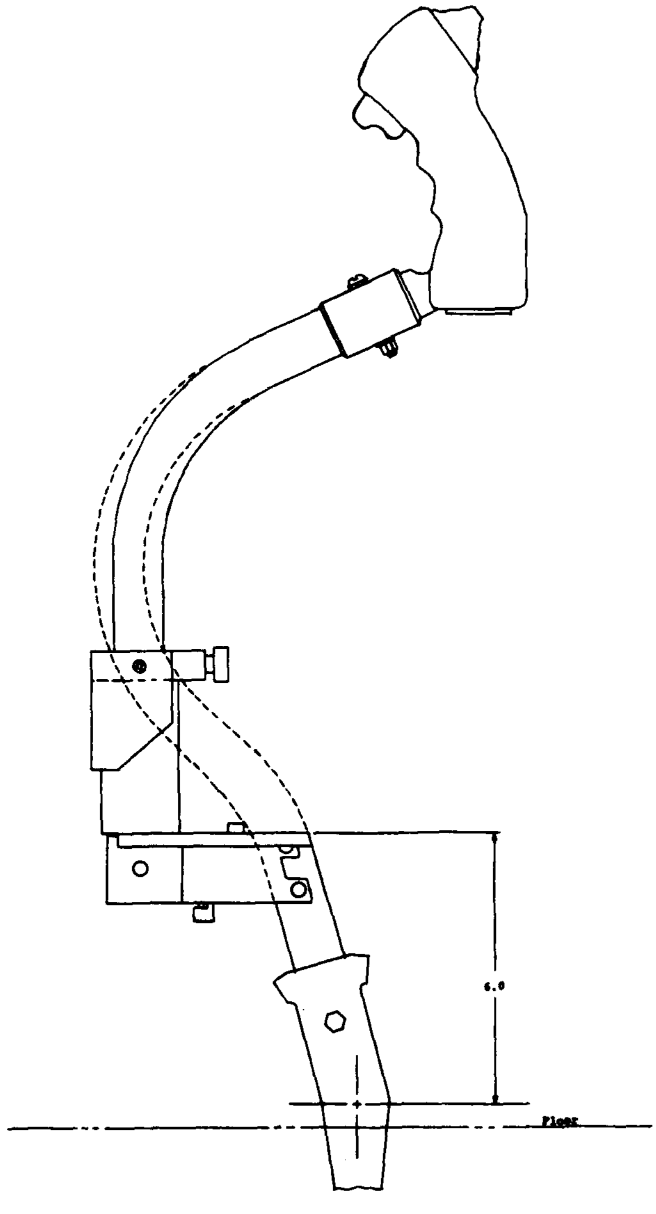


Figure 21. Crashworthy cyclic control stick - UH-60A Black Hawk helicopter.

A 2-in. increase in the height of the remaining stub was included to assure clean separation and to achieve a maximum of common parts to both helicopters. The stub height is below the maximum allowable height determined by the computer simulation and test film review mentioned in the Crash Environment section. Figure 22 shows the crashworthy cyclic control stick adapted to the AH-1S Cobra helicopter. Because of the control linkage interface, it became necessary to raise the height of the remaining stub to fit the slip joint mechanism to the tube. The respective heights of the remaining stubs with reference to the floor of the aircraft are 6.49 in. and 6.70 in. for the UH-60A and the AH-1S. This corresponds to 6.0 in. and 6.8 in. above the respective pivot points. The height of the separating point above the pivot point must exceed 4 in., the suggested height in the Aircraft Crash Survival Design Guide (Reference 1), for these two helicopters since the existing UH-60A control stick receptacle itself is 3.2 in. above the pivot point, and the hardware attached to the AH-1S cyclic control stick exceeds 4 in.

The offset of the centerlines of the tube segments was also increased over the conceptual drawing to clear the control linkage interfaces and mechanical stops in both helicopters. The increase assures positive separation without interference in all control positions.

The differences between the installation of the crashworthy cyclic control stick into the UH-60A Black Hawk and the AH-1S Cobra helicopters are at the interfaces of the control grip and the control linkages with the stick. The Black Hawk control linkage interface uses a claw fitting attached to a short section of tube which plugs into the socket for the existing control stick. For the Cobra helicopter, the existing control stick is cut off 1.5 in. above the "bell" fitting, and a claw fitting is slipped over the stub and secured in place.

The grip ends of the stick differ only in that the UH-60A Black Hawk tube ends with a male fitting for the grip attachment and the AH-1S Cobra tube ends with a female fitting. The center sections from the dovetail portion of the slip joint fitting to the height adjustment collar are identical for both aircraft.

A detail of the slip joint (Figure 23) shows the adjusting wedge used to remove clearances from the needle bearings. The test article slip joint consists of two solid components - the dovetail and the claw. In place of the two-piece claw of Figure 18c, a one-piece claw with a movable wedge was used. With the wedge retracted into the joint, there was enough clearance to load and position the needle rollers. To remove the clearance and any looseness in the joint, the adjusting wedge screw can be advanced against the dovetail. This pulls the wedge out of the joint slightly, and evenly compresses the needle rollers to provide a rigid joint. The slip joint is then free of any lateral or longitudinal play, but is still capable of releasing in the vertical direction with little resistance.

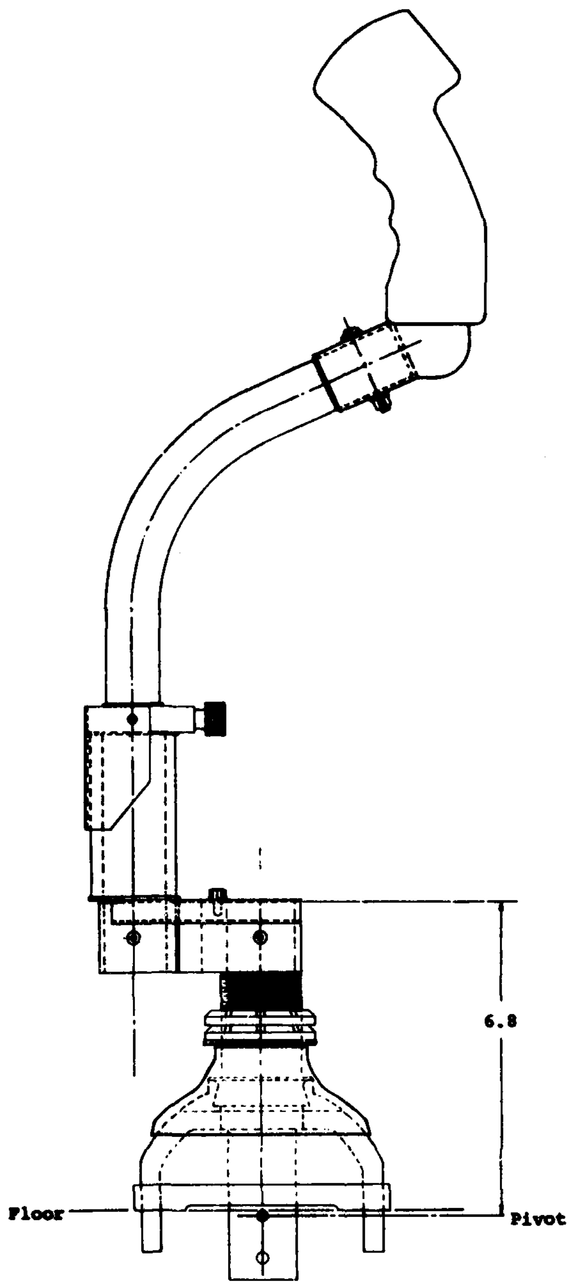


Figure 22. Crashworthy cyclic control stick, AH-1S Cobra helicopter.

To lock the joint until it is released by the crushing of the energy absorber, the fork is inserted into a space between the dovetail fitting and the energy absorber and fastened to the claw. An adjustment screw in the dovetail removes any vertical looseness.

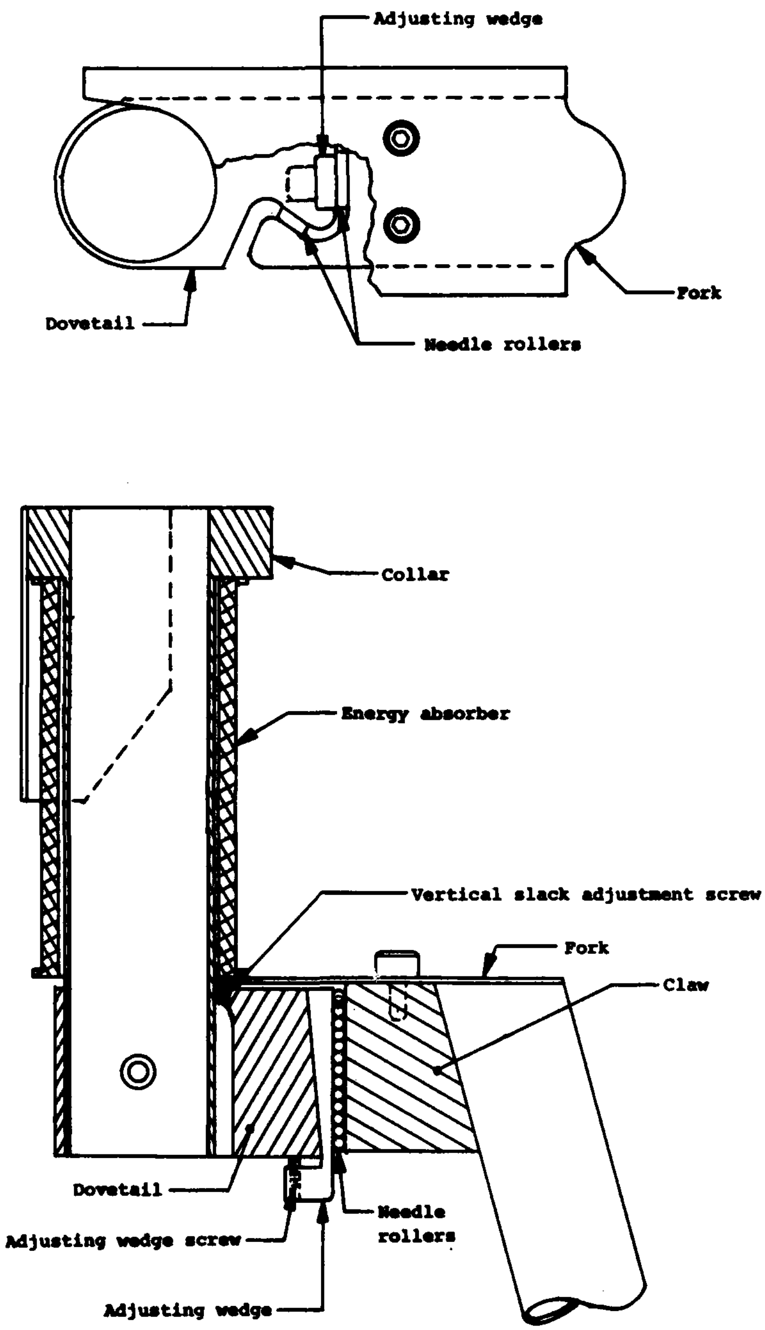


Figure 23. Slip joint detail.

Selection of the energy absorber was important to the operation of the crashworthy cyclic control stick. The selected energy absorber had to fit the envelope allotted, withstand static axial crushing loads of 100 lb, and crush smoothly at a load of 120 to

160 lb to be most effective. For this application, a Tube-core* honeycomb cylinder was chosen because it could meet these criteria at a minimum weight and volume. The cylinders used weighed only .41 oz.

Height adjustment in this design was accomplished by using a smaller tube which telescoped inside the tube rigidly attached to the dovetail fitting. A thin sleeve of acetal material was inserted between these tubes to lessen the friction during height adjustment. The sliding tube was held at the desired height by a spring plunger installed in the collar on the outer tube which engaged holes in the sliding tube. Height was adjustable 2 in. up or down from nominal in 1/2-in. increments.

Overall, the final design presented a number of desirable features. The slip joint with roller bearings is simple and can be expected to be reliable during both normal operations and a crash. No latches or other mechanisms which could bind or fail are included in the design. For complete separation, the impact force must continue for 1-1/2 in. of travel under constant resistance from the energy absorber, making accidental release unlikely. This release force also needs to be vertically oriented, so separation during normal operation is improbable. Only the movement of the stick caused by the crewmember impact during a crash can cause separation. After the joint separates, the stick is deflected off its base to further minimize any hazard.

The crashworthy cyclic control stick in the tested configuration would add a total weight increase of approximately 3.5 lb to each helicopter, with the height adjustment mechanism contributing 1.12 lb of that increase.

STATIC TESTING

To prove the ability of the crashworthy cyclic control stick to withstand the emergency operational loads specified in MIL-S-8698, deadweight static testing was performed on the four test article sticks (Figure 24). These tests were performed in the forward, aft, and lateral directions on each stick with loads of 200 lb longitudinally and 100 lb laterally.

Each test article stick was mounted in a rigid test fixture with a socket fitting similar to that of the UH-60A helicopter. This mounting provided a stiff, rigid base for the sticks so that only cyclic control stick characteristics were observed. The base held the sticks in the neutral position, and tests were performed with the height adjustment of the stick at the nominal position.

To place the loads at the specified point, the top of the grip, a grip simulator with the approximate dimensions of the actual grip

*Registered Trademark, Hexcel Corp.

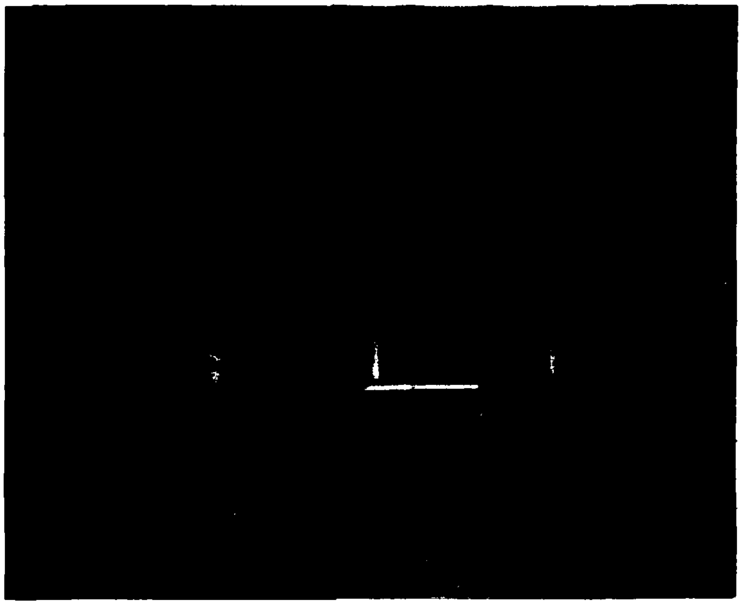


Figure 24. Four test article sticks used in deadweight static testing.

was constructed of rigid steel tubing. This grip simulator was stiffer and more rigid than the actual grip to eliminate any grip characteristics from the observed results.

The test base was attached to a vertical beam on the side of a large, rigid loading frame so that the normally vertical axis of the stick was horizontal. The loading frame is constructed of 10-in.-deep structural steel I-beams to provide sufficient rigidity to the mounting structure so that the cyclic control stick loading and deflection measurements could be taken without the need to correct for loading frame deformation. A potentiometric displacement transducer was attached to the grip attachment bolt to measure the stick deformation. The output of this transducer was recorded and stored on a digital waveform analyzer and disk memory. A summary of test instrumentation used in the static and dynamic testing is included in Table 2.

The stick was then loaded with the specified weight, which was verified by a platform scale; the weight was raised and released by a manual winch. Results of the static testing are shown in Table 3. Because of the symmetry of the cyclic control stick, one lateral test was performed on each article, serial numbers 1 and 3 to the left, the others to the right.

Posttest inspection of the test articles revealed no joint or energy absorber damage or movement. The claw fitting-to-lower tube rivets showed signs of shear deformation and some loosening. All

TABLE 2. TEST INSTRUMENTATION

Item	Instrument	Type	Manufacturer	Model	Range	Response	Accuracy, Full Scale (percent)
1	Load Cell	Strain Gage	Interface	1210-AO-2k	2000 lb	NA	0.1
2	Displacement Transducer	Potentiometric	Celesco	PT-101-10C	10 in.	100 G	0.1
3	Signal Conditioner	Bridge Offset	Bell & Howell	1-183	±1 V	DC to 30 kHz	0.1
4	Digital Voltmeter	Digital	Valhalla	4440	±2 V	NA	0.05
5	Accelerometer	Unbonded Strain Gage	Bell & Howell	4-202	100 G	1250 Hz	0.75
6	Waveform Analyzer	Digital	Norland	3001	±100 mv to 100 V	Flat within 0.5% from DC to 60 kHz	0.75
7	Tape Recorder	Analog	Sangamo	Sabre VI	1 V RMS	2500 Hz	0.4
8	High-speed Motion Picture Camera	Locam	Redlake	51	500 fps	NA	NA
9	Scales	Platform	Metro Equip.	300TD	300 lb	NA	0.2

TABLE 3. STATIC TEST RESULTS*			
Serial No.	Deformation (in.)		
	Forward	Aft	Lateral
1	.10	.10	.10
2	.09	.08	.04
3	.13	.09	.05
4	.08	.06	.06

*Weights used for fore and aft tests were 202 lb, 101 lb laterally.

permanent cyclic stick deflections could be traced to the loosening of these rivets, an easily improved attachment.

The tab connections of the claw fitting to the lower tube section by blind rivets should be altered to the equivalent of the dovetail-to-tube attachment, with the fitting encircling the tube. Loosening of the rivets - the cause of the deflections noted - would be eliminated. This remedy for the deviation from the static test requirements was viewed as a straightforward approach; modified versions of the crashworthy cyclic control stick were not deemed necessary for dynamic testing.

DYNAMIC TESTING

The objective of the dynamic test was to demonstrate the function of the crashworthy cyclic control stick in a dynamic crash environment. Reference tests were also conducted on the cyclic control sticks presently being used in the UH-60A and AH-1S helicopters.

Each cyclic control stick was mounted in a relatively rigid test fixture attached to the loading frame (Figure 25). The test article did not include a control grip wire bundle, and the grip was simulated with a steel tube weldment which weighed approximately 1/2 lb less than the maximum allowable weight for the actual grip. An upper body strike on the control stick grip during a crash was approximated by the impact of a pendulum with a plastic foam surface. The analyses of the Crash Environment section show that downward head motion is halted by the restraint system within 12 in. after the impact point of the cyclic control stick. The pendulum achieved an impact speed similar to that predicted for head-stick impact by the computer simulation. Paper honeycomb was used to arrest the pendulum after travel in excess of that of interest to the test.

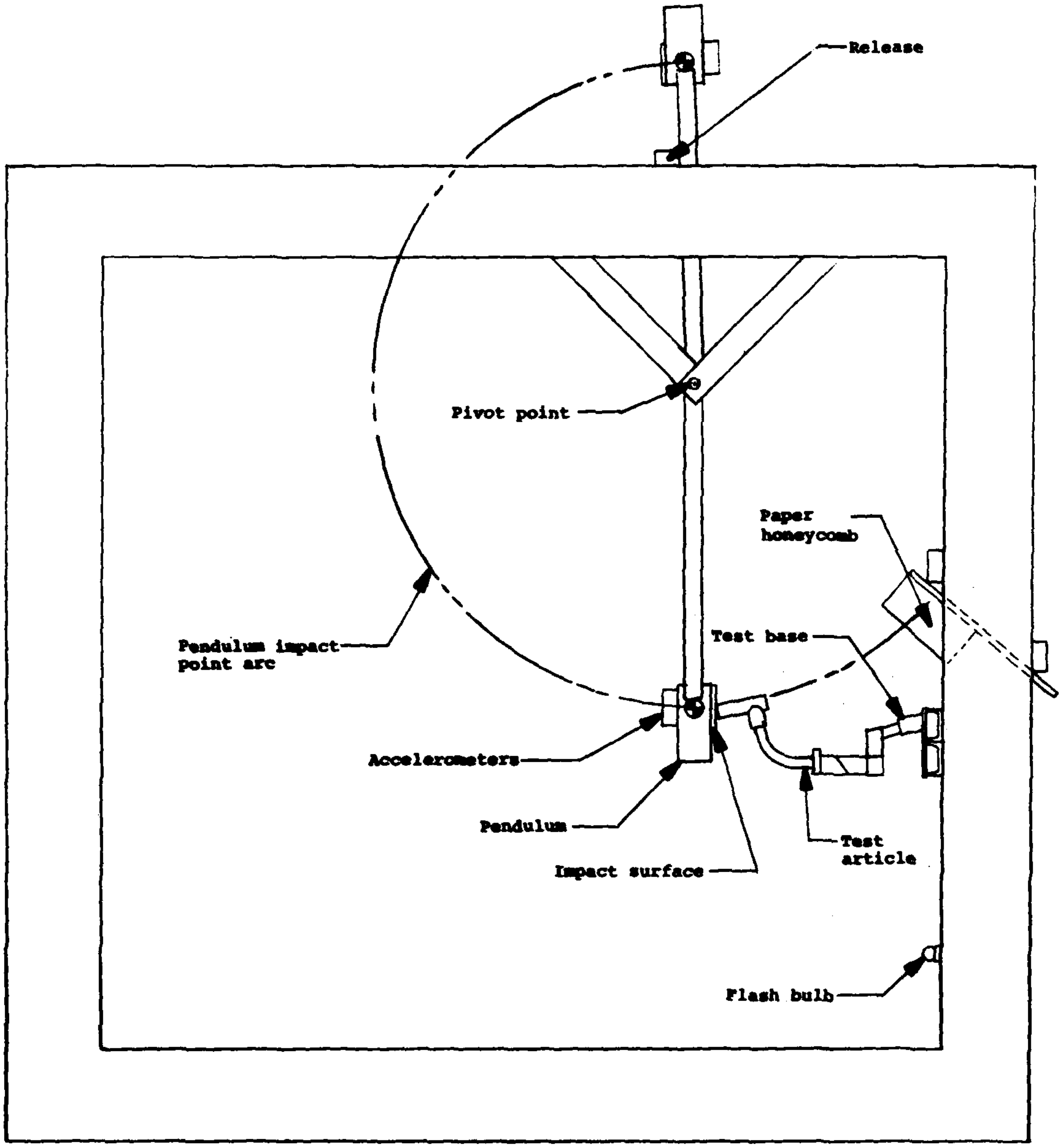


Figure 25. Dynamic test apparatus.

The pendulum was constructed of a solid piece of steel rigidly suspended by two steel members. Two strap (impact) switches were installed on the face of the pendulum: one for impact indication on the instrumentation, and one to activate a flash bulb for an impact indication on the photographic record. An impact surface of 1/4-in. Ensolite Type AL foam on a 3/8-in. plywood base was placed over these switches.

Three accelerometers were mounted on the rear of the pendulum directly opposite the impact point. Two of the transducers were mounted on an axis tangent to the pendulum swing arc: one as the primary sensor, one as a redundant sensor. The third accelerometer was mounted in the same area, parallel to the pivot axis. Any lateral accelerations due to any tendency of the pendulum to sway would be indicated by this transducer.

Testing was performed using a combination of the more severe conditions to be expected in a 95th-percentile survivable crash. The 75-lb weight of the pendulum approximately corresponded to the upper body weight of a 50th-percentile crewmember. The pivot point was placed approximately 35 in. from the impact point to provide a rough simulation of body motion and the desired velocity at impact requiring only gravitational acceleration. Impact velocity and direction were chosen from the SOM-LA computer simulation of the 50th-percentile Army pilot; these were 20 ft/sec, and zero degrees with respect to vertical.

A preliminary test and review of high-speed films showed the actual velocity to be approximately 20 to 21 ft/sec. The vertical impact on the stick exerts a greater bending moment on the separating joint than would an impact from aft of vertical. This vertical impact therefore results in the presence of maximum friction in the separating joint. Further evaluation of the SOM-LA computer simulation shows that, at this velocity and angle of impact, the 50th-percentile Army pilot has reached his maximum forward excursion, and the subsequent motion follows an aftward arc similar to that of the pendulum.

The instrumentation used for these tests are presented in Table 2. The calibration of these instruments is maintained in accordance with MIL-C-45662.

Four data channels were recorded by the primary and redundant data acquisition systems: 1) primary tangential accelerometer, 2) redundant tangential accelerometer, 3) lateral accelerometer, and 4) impact switch. The impact switch was on the face of the pendulum (under the padding). It indicated when the pendulum struck the stick, and this was recorded on one data channel so that the time scale could be referenced to a proper zero for the accelerometer channels. It also allowed correlation of the accelerometer data with the films, since another impact switch triggered a flash bulb in view of the cameras.

For each test, the pendulum was raised to a vertical position and released into free-fall to the impact position of Figure 26. Acceleration-versus-time plots are shown in Figures 27 through 30 for the test article sticks serial numbers 1 through 4, respectively. Conversion from acceleration to force was done with the formula: F(lb) = 75 x G, where F is the force acting on the grip end of the stick. Time sequence photographs from a high-speed film record are included in Appendix A.

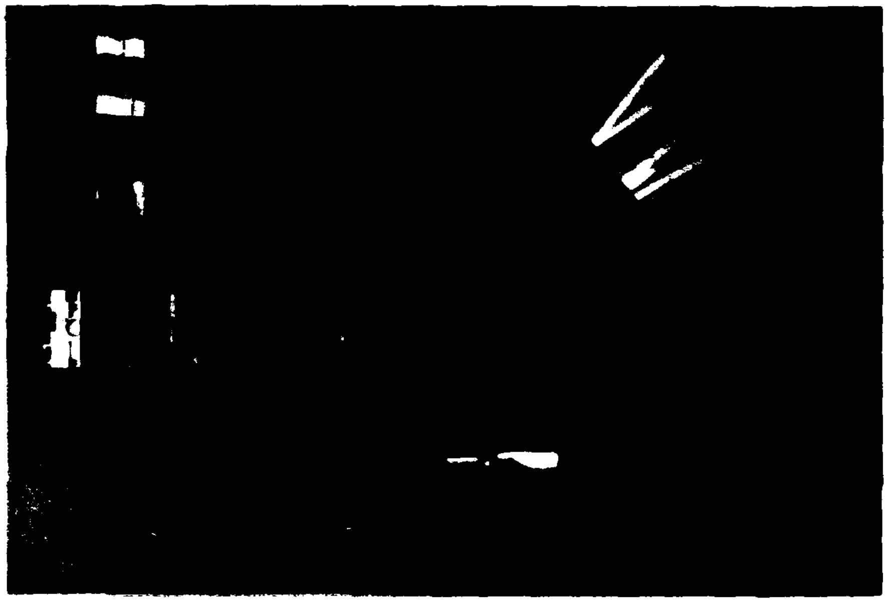


Figure 26. Test setup for dynamic tests.

Each crashworthy cyclic control stick performed as expected, with a sure separation and deflection off the slip joint base. The nearly triangular impact pulse was consistent at approximately 9.5 G with an 8-msec base for all four test articles. The secondary pulse of 4.5 G was due to the deflector contacting the fork and causing displacement of the upper section of the stick off the slip joint base. This was established by correlating the acceleration and film data through the use of their respective time scales. Posttest pictures of test article serial number 3 are shown in Figures 31 and 32.

In order to determine how much of the recorded 9.5-G pulse was due to joint friction and energy absorber crush and how much was due to the inertia of the stick, an additional test was performed. In this test the separating portion of the test article stick was suspended in the preimpact position using cotton string and then was struck by the pendulum in the same manner as the previous tests. The purpose of this test was to measure the inertial effects of impacting the motionless stick with the given test velocity and parameters. An acceleration-versus-time plot of this test is shown in Figure 30 for comparison with the test article response. As shown by the figure, the inertial pulse due to impacting the free stick in space with a 20-ft/sec velocity was roughly an 8-G triangular pulse of 8-msec duration. The difference in the maximum amplitude of these pulses is 1.6 G or 120 lb, the target resistance of the energy-absorber. Therefore, the slip joint performed nearly friction-free, as expected.

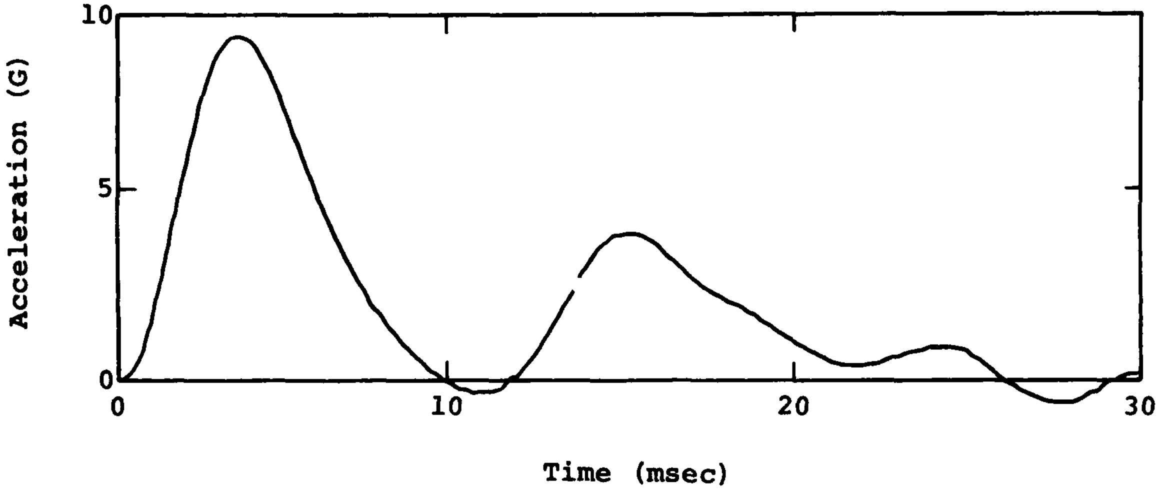


Figure 27. Test article acceleration-versus-time plot, serial number 1.

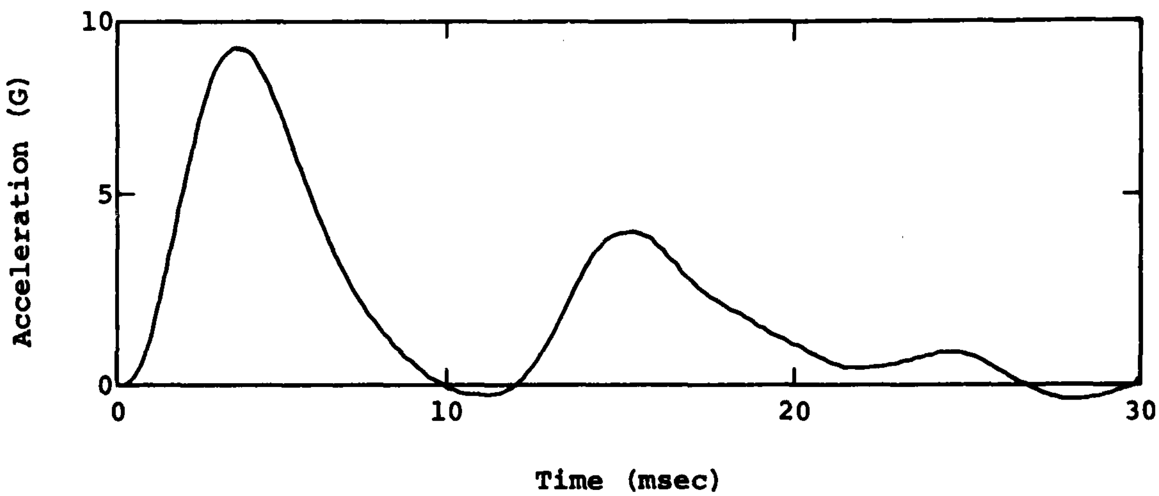


Figure 28. Test article acceleration-versus-time plot, serial number 2.

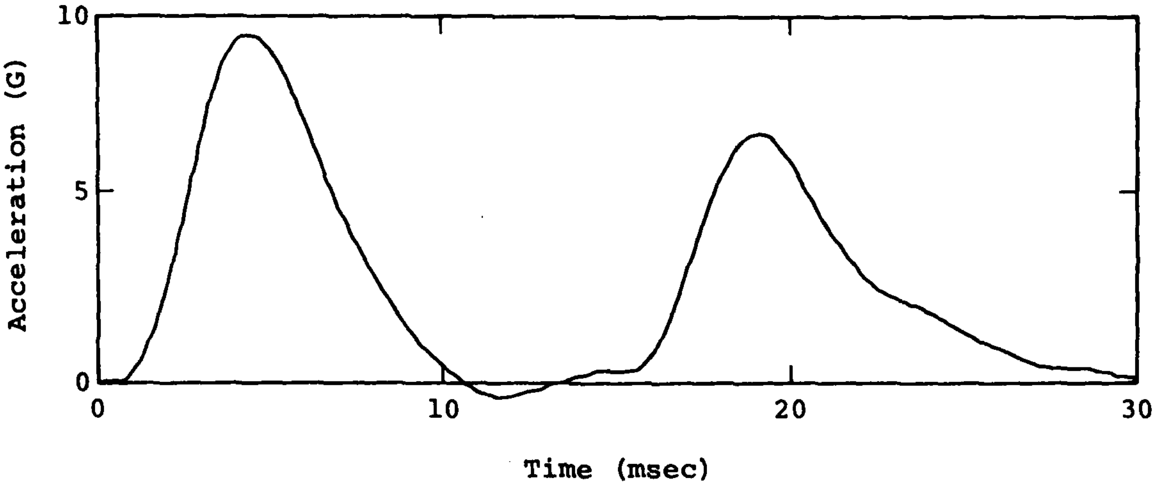


Figure 29. Test article acceleration-versus-time plot, serial number 3.

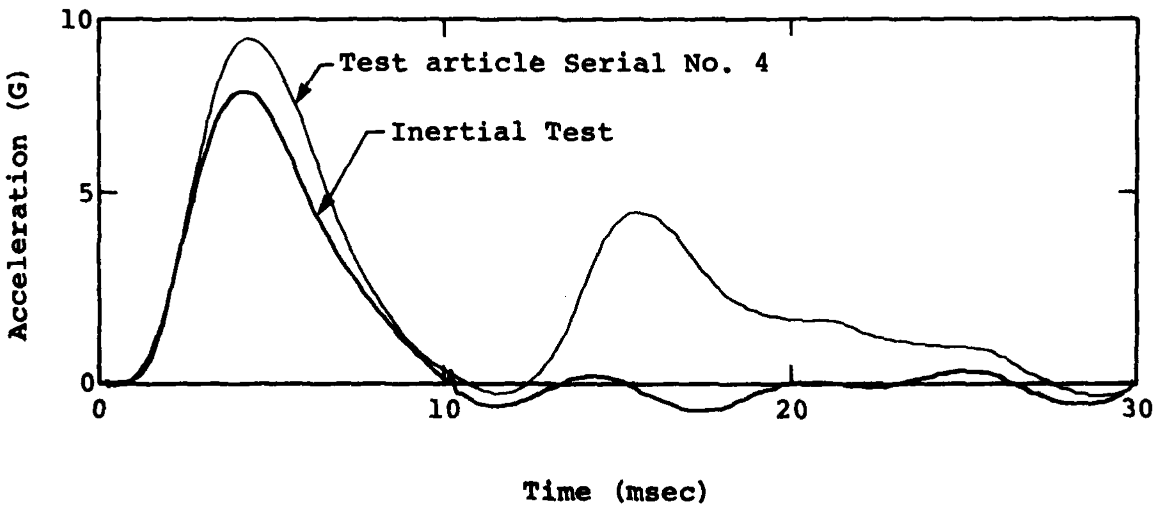


Figure 30. Test article and inertial test acceleration-versus-time plot, serial number 4.

Figure 31. Posttest view of test article serial number 3.

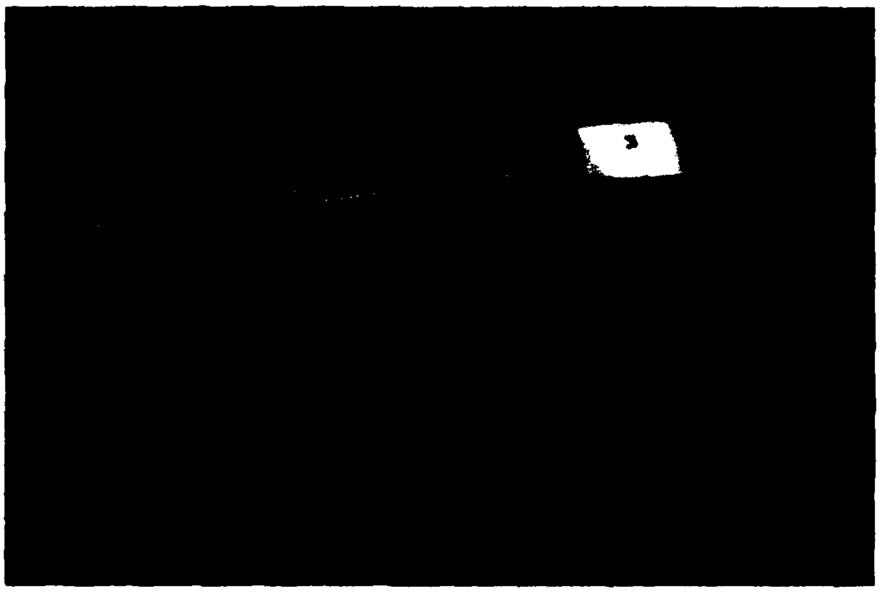


Figure 32. Posttest view of crushed collar, test article serial number 3.

Dynamic tests were also performed on the existing UH-60A Black Hawk and AH-1S Cobra cyclic control sticks. Pretest photographs of these sticks are shown in Figures 33 and 34. The existing UH-60A cyclic control stick is a continuous steel tube of 1.125-in. O.D. by .049-in. wall with a 0.62-in.-diameter hole located just above the control linkage end of the stick at an angle of 45 degrees left of the longitudinal axis for the wire bundle to exit the interior of the tube. Failure of the stick in the dynamic test occurred around the circumference of the tube through the center of this hole (Figure 35). A series of time sequence photographs are shown in Appendix A. The acceleration-versus-time plot is shown in Figure 36. This plot shows the impact pulse as triangular with a peak of 17 G and a total duration of 16.5 msec.

The existing AH-1S cyclic control stick was tested in the same manner. Its mounting was an approximation of the actual helicopter interface. The "bell" portion of the stick assembly was positioned on a flat plate with the lower tube section projecting through a hole. A piece of larger tubing was placed over the projecting tube section and fastened with a bolt through the existing control linkage attachment hole. The two jam nuts and Belleville washers on the shaft of the stick were tightened against the "bell" to securely capture the cyclic control stick.

Under the dynamic loading, three rivets holding the "bell" assembly to the tube sheared and allowed the tube to telescope through about three-quarters of an inch. As the loading continued, the grip simulator was torn out of the end of the tube. The pendulum travelled freely until the impact surface struck the jagged grip end of the tube. The cyclic stick, now loose in its base from the telescoping, deflected aftward as the pendulum continued on its arc until the forward motion of the pendulum was stopped by the stick.

The underfloor control interface for the AH-1S may have affected the test results, since it cannot be determined if the control linkage or adjacent structure would have prevented the telescoping. Analysis of the complete acceleration-time plot for the AH-1S stick (Figure 37) shows a first peak of approximately 17 G, 4 msec after impact, when the telescoping occurs. An increase to nearly 30 G at 8.5 msec after initial impact occurs when the grip simulator is torn from the stick. Total duration of these pulses is 13.5 msec. Pendulum travel continues to 50 msec after initial impact when the jagged end of the stick tore the impact surface off the pendulum. The stick is bent aftward at a constant 12-G resistance until the pendulum motion is stopped at 90 msec after impact. Posttest photographs are shown in Figures 38 and 39. A time sequence series of photographs is included in Appendix A. Little motion of the pendulum is discernbile from 64 msec after initial impact until the pendulum reverses direction at 90 msec after impact. For this reason, no time sequence photographs after 64 msec are included in Appendix A for the AH-1S cyclic control stick.

Figure 33. Pretest view of UH-60A Black Hawk cyclic control stick test setup.

Figure 34. Pretest view of AH-1S Cobra cyclic control stick.

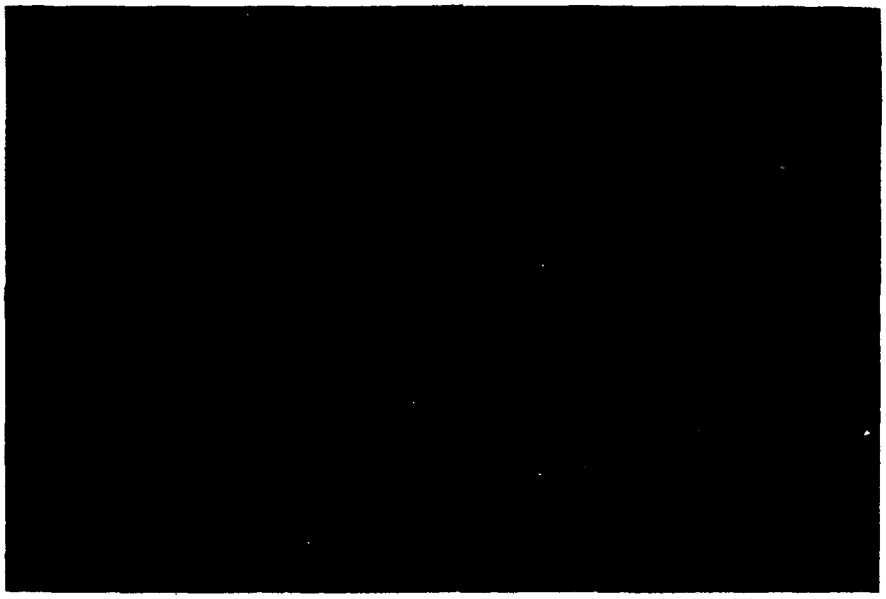


Figure 35. Posttest view of UH-60A Black Hawk cyclic control stick fracture.

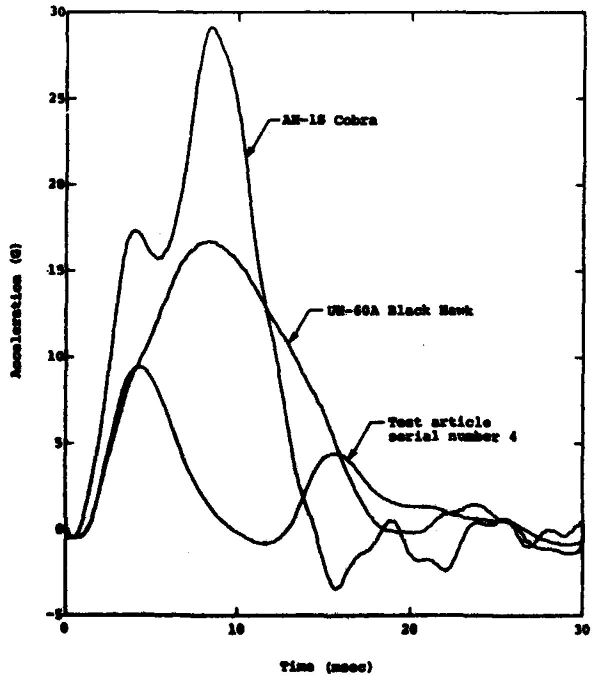


Figure 36. Existing UH-60A Black Hawk and AH-1S Cobra cyclic control stick acceleration-versus-time plot (test article serial number 4 shown for comparison).

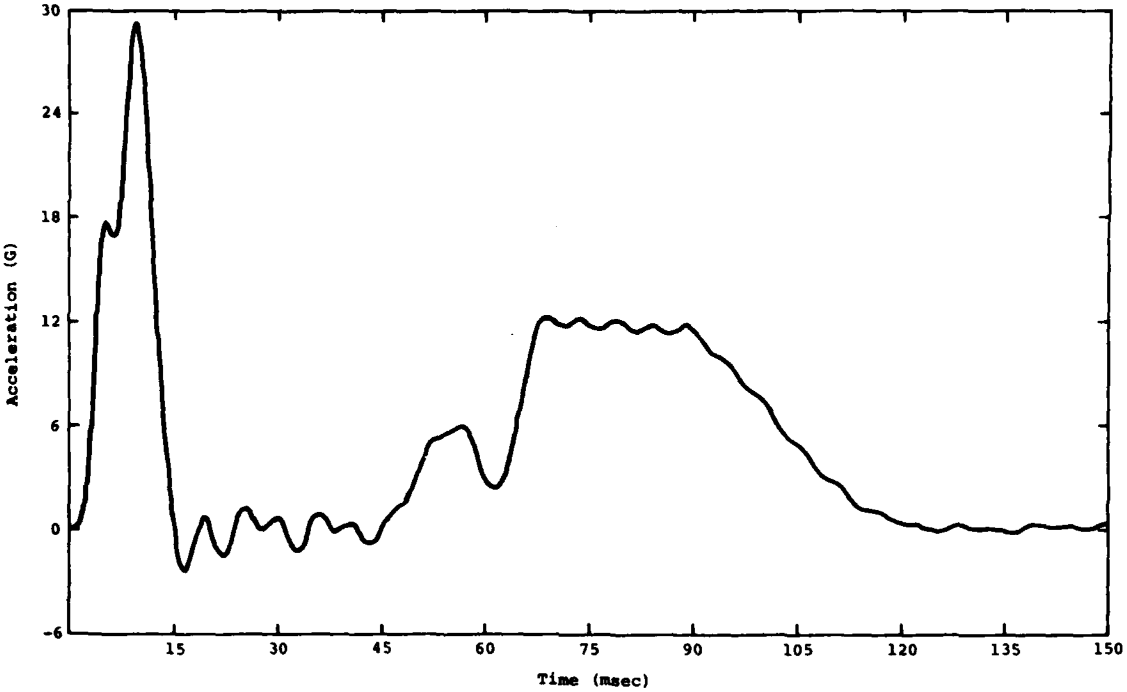


Figure 37. Existing AH-1S Cobra cyclic control stick acceleration-versus-time plot.

Figure 38. Posttest view of AH-1S Cobra cyclic control stick.

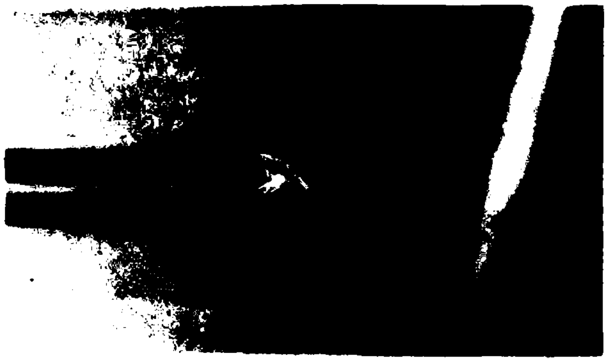


Figure 39. Posttest close-up view of AH-1S Cobra cyclic control stick.

Both existing cyclic control stick dynamic test results are plotted in Figure 36 along with the results of the crashworthy cyclic control stick serial number 4 for comparison. This figure includes data only up to 30 msec, since the Cobra stick and test article 4 produced no significant acceleration after this time. Peak and duration values for the primary peak of all tests are given in Table 4.

TABLE 4. PEAK AND DURATION VALUES FOR ALL TESTS

Stick	Peak (G)*	Duration (msec)
Serial Number 1	9.3	8.3
Serial Number 2	9.2	8.2
Serial Number 3	9.4	8.8
Serial Number 4	9.4	8.3
Inertial	7.8	8.2
UH-60A	16.7	17.2
AH-1S	29.1	13.7

*Multiply G values by 75-lb pendulum weight to obtain applied force.

The dynamic test apparatus was designed to approximate an upper body strike during crash impact. To maintain control over important test parameters, some aspects of an actual crash impact were deleted. Velocity and direction of the body impact were controlled by a rigid, weighted pendulum, so the articulation of the body joints and weight distribution was missing. Lateral and twisting motions were also rigidly controlled, and by necessity, absent. Each cyclic control stick was struck in a similar manner with the same apparatus. The results from these tests are, therefore, an accurate relative comparison and should be viewed as such.

RETROFIT OF UH-60A BLACK HAWK AND AH-1S COBRA

The crashworthy cyclic control stick that was designed and tested in this program can be installed in the UH-60A and AH-1S helicopters, with a minimum of time and expense. The retrofit could easily be performed in the field without special equipment. A brief description of the installation requirements for each aircraft follows.

UH-60A BLACK HAWK

Retrofit of the crashworthy cyclic control stick into the UH-60A Black Hawk would follow the maintenance instructions for replacement of the existing cyclic control stick. The only changes required for the UH-60A would be replacement of the boot around the base of the stick with a version compatible with the crashworthy retrofit and installation of a conspicuous safety placard stating the nature of the modification and the not-to-exceed static download for the cyclic stick.

Materials required to successfully retrofit the crashworthy cyclic control stick into the UH-60A in either the pilot or copilot's position are:

- One crashworthy cyclic control stick with grip and wire bundle (UH-60A upper tube and claw fitting)
- One revised boot assembly
- One safety placard.

AH-1S COBRA

Retrofit of the crashworthy cyclic control stick into the AH-1S Cobra would be slightly more complex. The simplest approach would be to cut off the existing cyclic control stick 1.5 in. above the top of the threaded sleeve on the shaft of the stick. The severed stick and existing wire bundle would be removed and a strengthening doubler attached with rivets to the interior of the remaining tube. The existing Belleville washers on the stick could be replaced with modified versions. The tube would then be match drilled to the claw fitting which fits over it and is bolted in place. To complete the installation, a hole would be cut in the floor panel to allow passage of the grip switch wire bundle connector to mate with the existing connector below floor level. The floor coverplate would be attached over this hole after the wire bundle was encircled by the grommet and positioned in a notch in the coverplate. A safety placard must also be installed in a place conspicuous to the pilot, which would state the nature of the modification and the not-to-exceed static download for the cyclic control stick.

Materials needed to successfully retrofit the crashworthy cyclic control stick into the AH-1S pilot position are:

- One crashworthy cyclic control stick with grip and wire bundle (AH-1S upper tube and claw fitting)
- One tube I.D. doubler
- Two modified Belleville spring washers
- Three attach rivets for doubler
- One AN4C21 bolt, AN1211552 nut, and safety wire
- One floor coverplate with grommet, attaching screws, and clip nuts
- One safety placard.

DISCUSSION OF RESULTS

Although the crashworthy cyclic control stick designed and tested during this project functioned as intended, it is difficult to accurately assess the probability of injury due to impact with this stick. There are uncertainties both in human tolerance levels and in relating test results to an actual crash.

Table 1 shows human tolerance levels used to determine acceptable separation loads for the stick. Only amplitudes, and not durations, were readily available, so it was difficult to properly apply these data to a dynamic situation. Also, some minimum injury levels are slightly below the minimum permissable loads required by operational constraints. Based on these tolerance data and operational requirements, a load range of 100 to 160 lb was selected for stick separation. The 60-lb load tolerance was selected to permit economical fabrication of prototype honeycomb energy absorbers. This tolerance could be economically reduced in a production design. It was realized that this 100- to 160-lb range might not prevent all injury, but separation loads lower than 100 lb are not permissable operationally.

Since operational load requirements are specified statically, the 100-lb minimum separation load had also to be a static requirement. Therefore, the separating joint had to produce at least 100 lb of resistance. Any loads due to the inertia of the moving portion of the stick would be in addition to this minimum static load. During the dynamic pendulum tests, peak loads of approximately 700 lb were obtained, as shown by Table 4. While these loads are one-half to one-third the loads obtained with the conventional sticks, they are well over the minimum tolerance levels shown in Table 1 for the face and neck. They are also over the mean value for most of the facial structure. However, presently available data does not permit a precise assessment of injury potential due to these loads. There are three reasons for this:

1. The data can presently be compared only in terms of peak loads. Without having durations associated with the tolerance data, the probability of injury cannot be adequately assessed for the impact pulses obtained in the test. A comprehensive literature survey could perhaps provide this data.

2. The impact pulses obtained in these tests do not indicate the nature of the pulse which would result if a crewmember struck the stick. The spring rates and damping characteristics of a human being would be quite different from those of the pendulum, and a different pulse would result. The test data in this report are really only useful for relative comparisons between sticks.

3. The mass used in the test was concentrated. For a human, the mass is distributed and various segments are hinged together. Therefore, the response would differ.

Whatever the actual dynamics of the stick/human impact, the design developed in this program can be expected to reduce injury appreciably. If further research shows that further delethalization of the cyclic control stick is desirable, then the only solution is to change the inertial characteristics of the stick. This is because the joint separation load represents only about 20 percent of the peak load and that cannot be reduced because of operational requirements. Therefore, 80 percent of the impact force is developed in accelerating the mass of the stick and it is this portion of the force that must be reduced. Also, as noted in the Dynamic Testing section, an actual grip with cables would be heavier than the grip simulators used in the tests.

The most direct method of reducing the inertial load is to reduce the weight of the moving portion of the stick. An advanced prototype or production design could reduce the weight of the moving portion of the stick by perhaps 25 percent. Further reductions may be possible if composite materials were used in the construction and if the grip were redesigned.

The maximum inertial load could also be decreased if some crushing material were installed on the top end of the stick. If this were done, the stick would be accelerated at a lower rate for a longer period of time. The result would be a lower peak load on the occupant. This would, of course, require redesign of the grip to provide a softer end.

It could be assumed that the G loads acting directly on the stick in a crash will reduce the force required to separate it. However, these loads will peak long before the occupant strikes the stick, and may not be of much benefit. Whatever methods might be used to reduce the inertial forces, if it should be deemed necessary, the joint developed in this program should be compatible with the resulting configuration. This joint separates at the minimum vertical load permitted by operational constraints and provides strength in the fore and aft and lateral directions that is similar to that of existing sticks.

CONCLUSIONS

The objectives of the program - to design, fabricate, and test a crashworthy cyclic control stick adaptable to the UH-60A Black Hawk and AH-1S Cobra helicopters - have been achieved. The concept of a crashworthy cyclic control stick which can separate under a reduced impact load during a crash within a safe proximity to the floor of the aircraft is feasible. Implementation of this crashworthy cyclic control stick could present a comparatively lesser injury potential to the helicopter flight crew.

Many factors were examined and many alternate designs conceived and evaluated. The slip joint concept selected provided optimum performance within operational and functional constraints. The design incorporates one-axis, low friction movement of the single moving joint during a crash impact; it is activated by the load applied to the stick by the crewmember. Also present is an energy-absorbing stroke which provides a fail-safe feature against inadvertent separation. The energy absorber must be crushed before the joint can separate; therefore, short duration impacts will not separate the stick.

Static test requirements per MIL-S-8698 were met. The slip joint stick is capable of supporting all emergency operational loads.

Dynamic tests were performed which approximated the impact of the cyclic control stick by an upper body using a five-point restraint. Relative comparisons of the crashworthy and existing UH-60A and AH-1S cyclic control sticks show the maximum amplitude of the initial impact forces of the crashworthy version to be reduced by 44 and 68 percent, respectively, relative to the existing UH-60A and AH-1S sticks. There is also up to a 50-percent reduction in the duration.

The crashworthy design proved successful by meeting the static load requirements and demonstrating a significant reduction in the peak and duration of the impact pulses. Eight G of the 9.5-G pulse at impact was due to stick inertial loads; the slip joint design performed essentially friction-free under the loads and moments at impact. Disregarding inertial loads, the stick assembly stroked at approximately the design load of the honeycomb energy absorber during the dynamic test.

The program successfully demonstrates that an operationally acceptable crashworthy cyclic control stick is feasible for both aircraft involved. This device can provide ~eliable crash protection in a form physically compatible with existing aircraft while still providing a rigid control assembly with a fail-safe release.

RECOMMENDATIONS

Further testing is recommended with full-scale systems using a HYBRID III anthropomorphic dummy and UH-60A energy-absorbing seat to duplicate the actual crash environment as realistically as possible. These tests would supplement the previous dynamic tests and provide further assurance of the crashworthy cyclic control stick design. The tests should be conducted with the cyclic stick mounted on load cells to directly measure the inertial loads on the stick and the force applied to the stick by a human-like object. Inertial effects of structural impact pulses upon the stick could be observed and alternate sticks could be substituted during the course of these tests to evaluate the effectiveness of a "soft" grip approach to further reduce the impact pulse of the crewmember.

Following these tests a production design effort is recommended which would culminate in a crashworthy cyclic control stick production run and retrofit into the applicable aircraft. Considerable emphasis should be placed on weight reduction, since most of the load applied to the occupant by this stick design is due to the inertial effects of the moving portion of the stick.

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6. Hodgson, V. R., "Tolerances of the Facial Bones to Impact," <u>American Journal of Anatomy</u>, Vol. 120, Jan 1967.

APPENDIX A

TIME SEQUENCE PHOTOGRAPHS OF DYNAMIC TESTS

This appendix presents excerpts from high-speed motion picture film of the dynamic tests of existing and newly developed cyclic control sticks; the film speed was 500 fps. Figures A-1 and A-2 show the Simula-developed control stick. The existing UH-60A and AH-1S cyclic control sticks are shown in Figures A-3 and A-4, respectively.

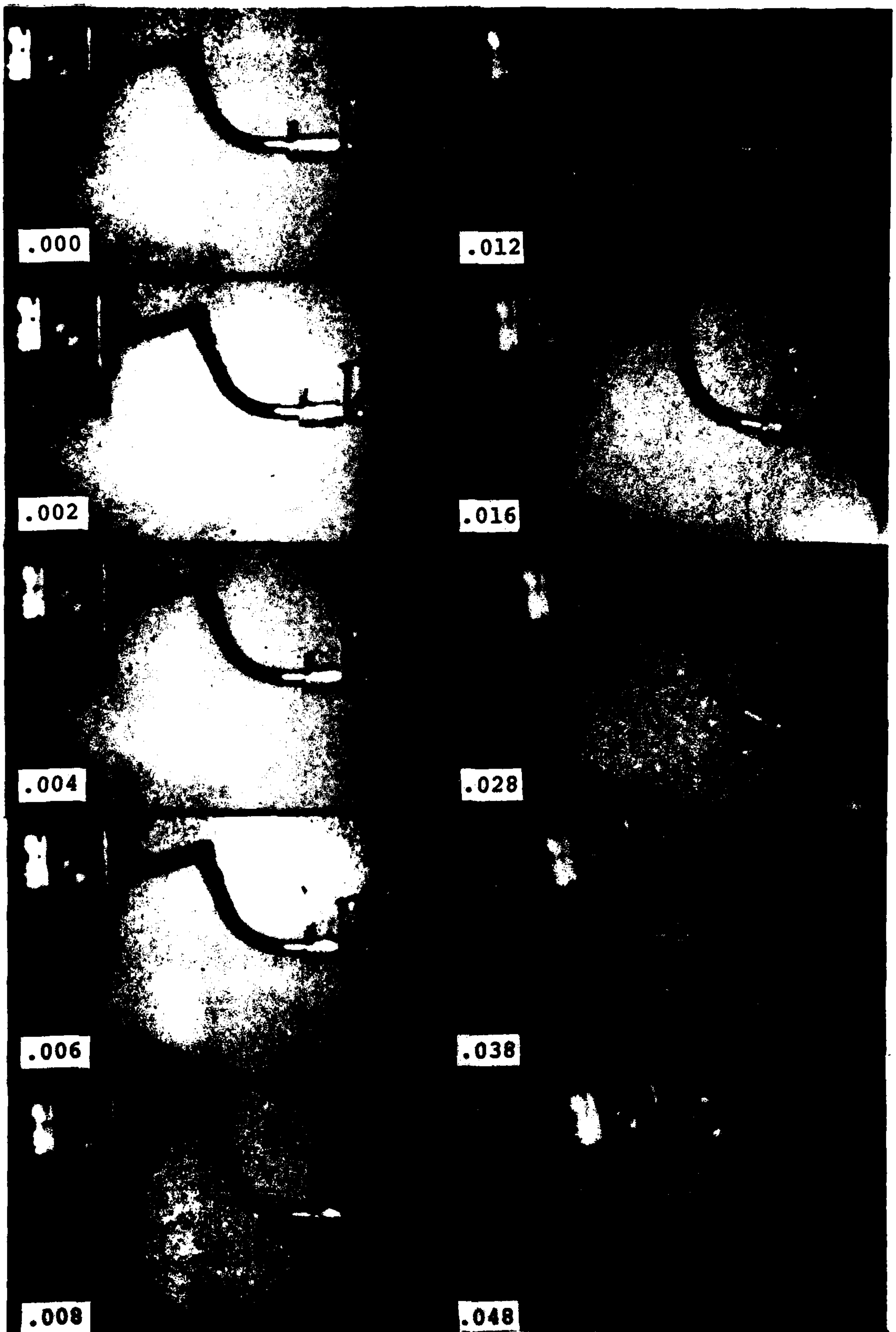

Figure A-1. Simula-developed cyclic control stick, serial number 1 - overall view.

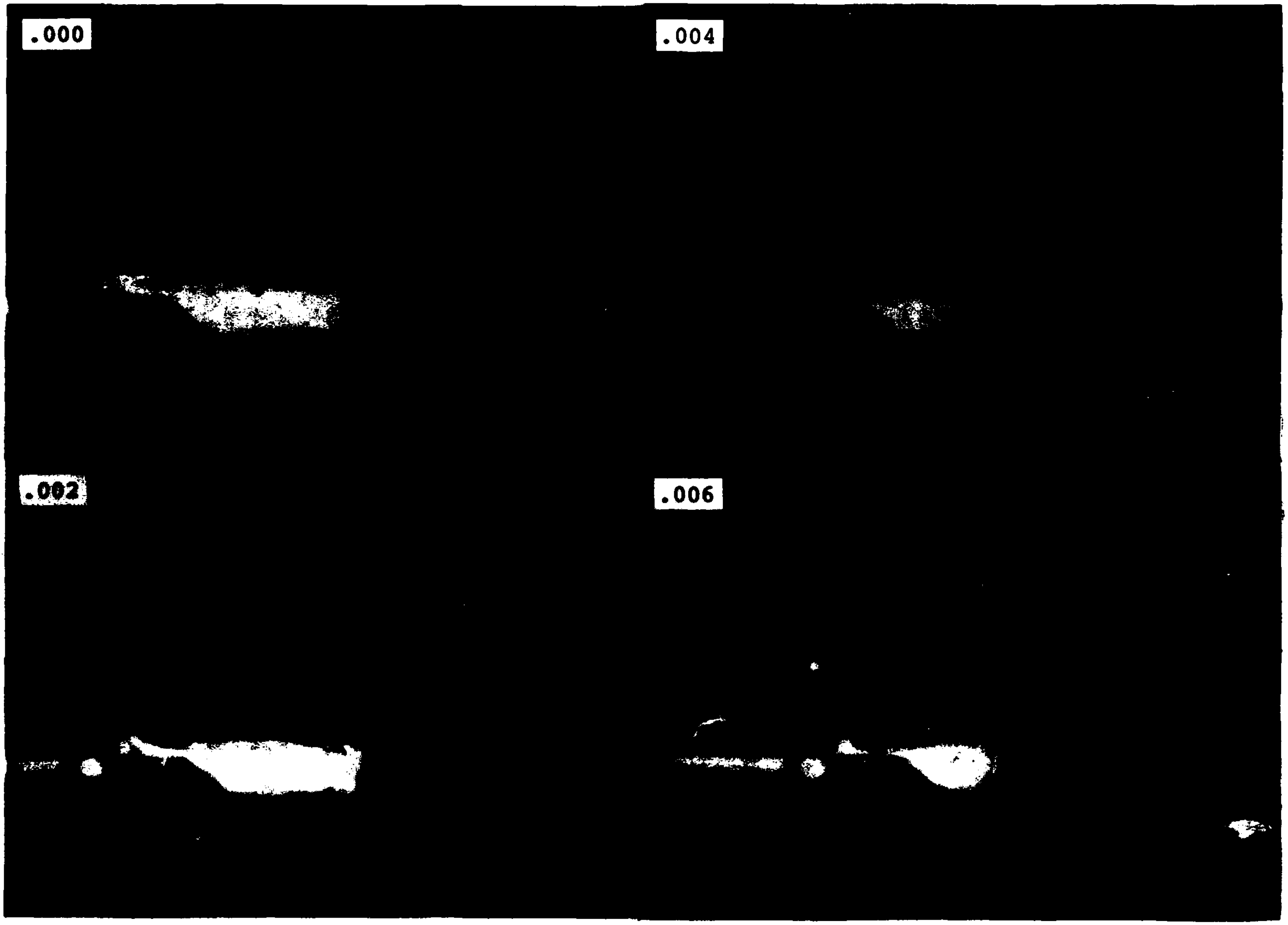

Figure A-2. Simula-developed cyclic control stick, serial number 1 - closeup view.

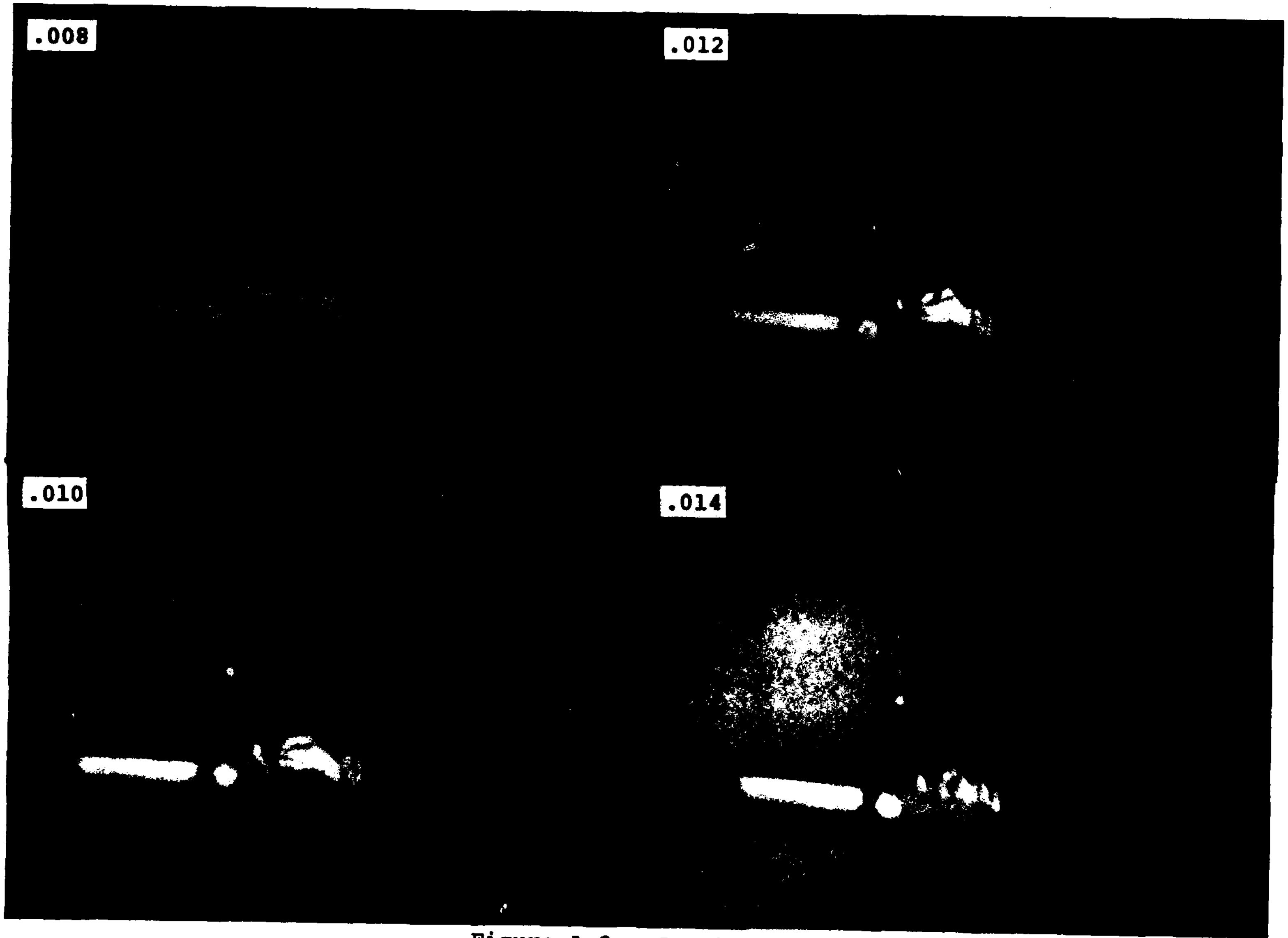

Figure A-2. Continued.

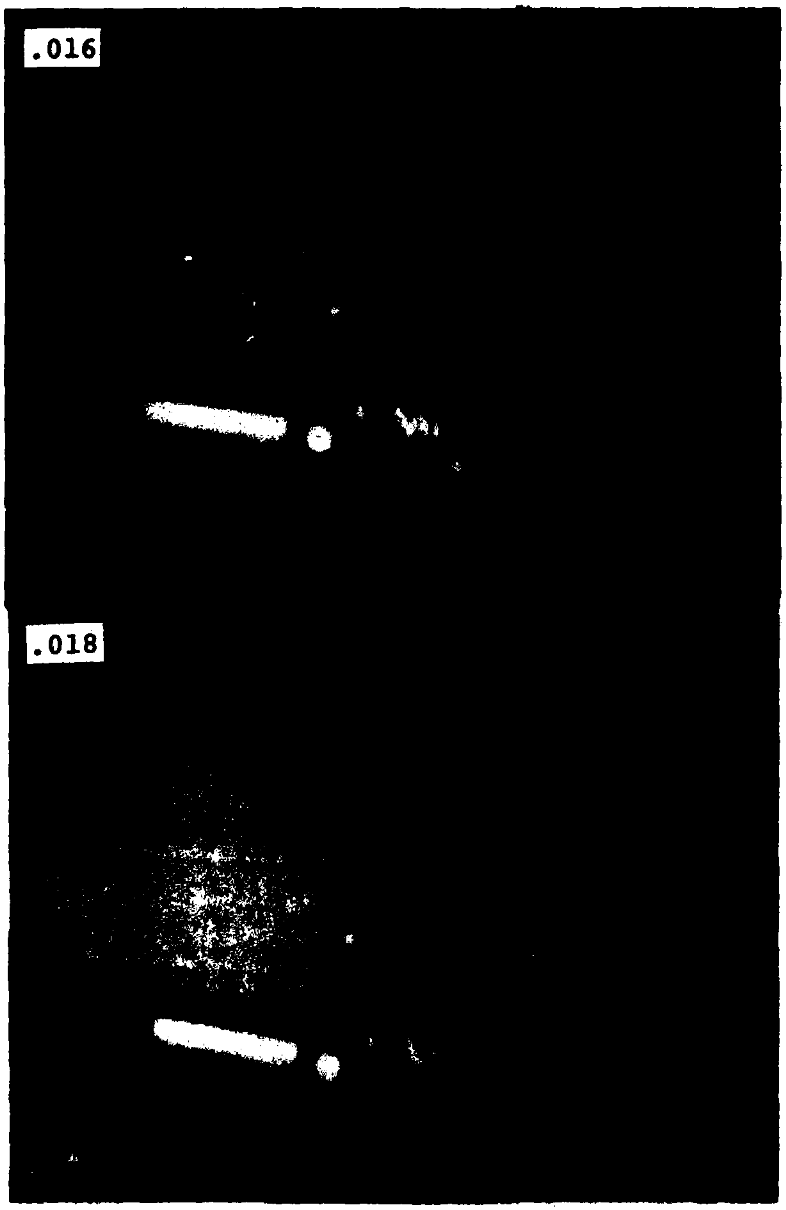

Figure A-2. Continued.

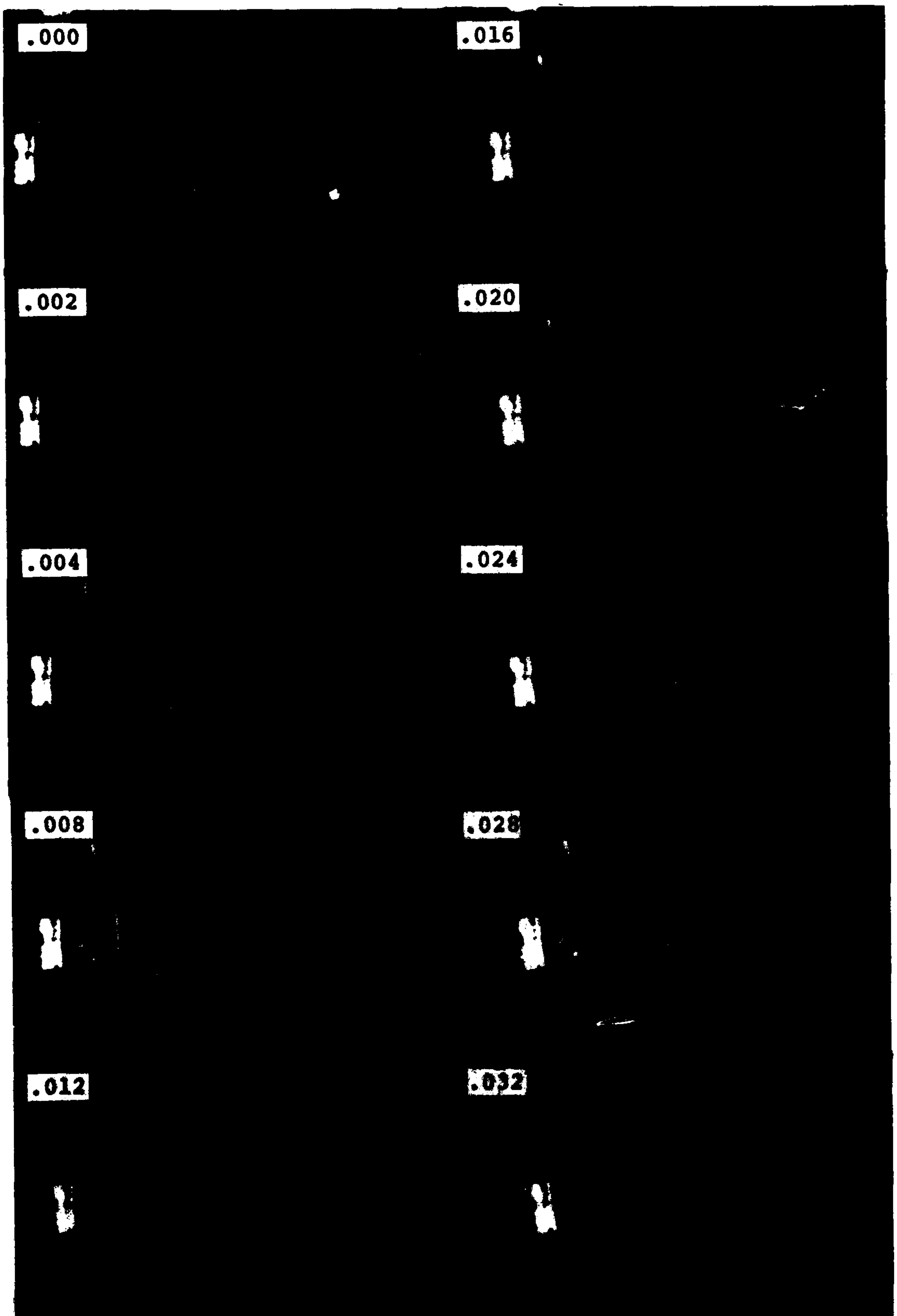

Figure A-3. Existing UH-60A Black Hawk cyclic control stick.

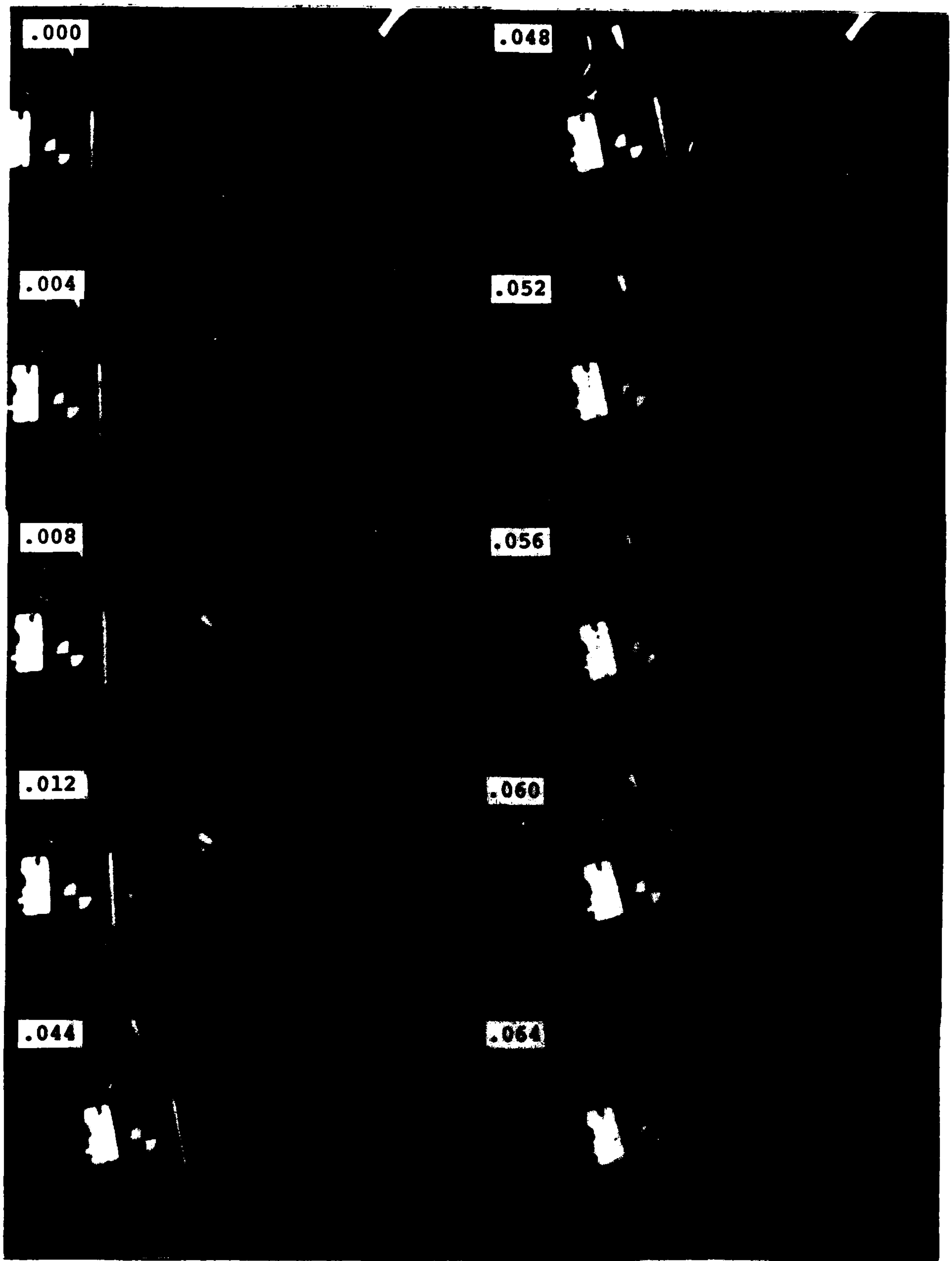

Figure A-4. Existing AH-1S Cobra cyclic control stick.

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